MAGNETIC RECORDING MEDIUM, PROCESS FOR PRODUCING SAME AND
MAGNETIC DISC APPARATUS

BACKGROUND OF THE INVENTION

This invention relates to a magnetic recording
medium which has an excellent reliability and permits
magnetic recording at a high density, a process for
5   producing said magnetic recording medium, and a magnetic
disc apparatus used as an auxiliary storage for computer.

Magnetic disc apparatus used in storages such as
large computers, workstations, personal computers, etc. are
growing in importance year by year and have been increased
10   in capacity and reduced in size. For the capacity increase
and size reduction of the magnetic disc apparatus,
increasing their density is indispensable. An example of
technique for realizing the density increase is the
reduction of the distance between the magnetic recording
15   layer of a magnetic recording medium and a magnetic head.

Magnetic recording media produced by sputtering
have comprised a protective film for protecting a magnetic
film against sliding on a magnetic head. The reduction of
thickness of the protective film and the reduction of the
20   distance between the protective film surface and the
magnetic head are the most effective means for reducing the
distance between the magnetic recording layer and the
magnetic head. As the protective film, carbon films formed
by DC sputtering, RF sputtering (JP-A-5-174369) or CVD

(JP-A-4-90125) are most generally used. For obtaining a
protective film having a higher strength, a method of
incorporating nitrogen atoms, hydrogen atoms, etc. into the
film (JP-A-62-246129 and JP-A-5-22556) has been generally
5 adopted.

        As a conventional interface method for a magnetic
recording medium and a magnetic head, there is contact-
start-and-stop (CSS) method in which at the time of non-
working, the magnetic head is stationary in contact with
10 the magnetic recording medium at a predetermined position
on the medium where very small concavities and convexities
have been formed for preventing adhesion between the
magnetic recording medium and the magnetic head, and at the
time of working, i.e., the time of record writing, record
15 reading or waiting, the magnetic head is lifted while
keeping a very narrow space between the magnetic head and
the magnetic recording medium.

        In the case of magnetic disc apparatus to which
this method is applied, the problem of wear and fracture of
20 the protective film of a magnetic recording medium caused
by contact or friction between the magnetic recording
medium and a magnetic head at the beginning or end of work-
ing becomes more serious with a reduction in the thickness
of the protective film. Also at the time of working, the
25 problem of wear and fracture of the protective film caused
by accidental contact between the magnetic recording medium
and the magnetic head becomes more serious with a reduction
in the distance between the protective film surface of the

magnetic recording medium and the magnetic head.

It has been proposed that the durability of the protective film is improved by making the thickness of the protective film in an area where CSS is carried out
5   (hereinafter referred to as CSS area), larger than that in an area where data are written (hereinafter referred to as data area) (JP-B-60-23406). However, no sufficient effect can be obtained by merely changing the film thickness because at present, the increase of the capacity and the
10 reduction of the size are absolutely necessary. In detail, the above-mentioned data area has to be as wide as possible in order to record data as much as possible in the limited area of a disc. Therefore, the CSS area and the data area are unavoidably adjacent to each other. In such a
15 condition, it is industrially difficult to make the film thickness in the CSS area widely different from that in the data area. Even if such a thickness change is realized, the reference position of the disc surface is abruptly changed when a head is allowed to seek between the CSS area
20 and the data area. Thus, the thickness change causes an attitude change.

Therefore, the possible thickness difference is at most about 5 nm, and merely changing the thickness of a single film has been hardly effective. In addition, a
25 thinned portion of about 10 nm thick of the protective film in the data area has to have a certain degree of hardness because it is easily fractured by its accidental collision with a magnetic head. However, when the protective film

has such a hardness, it is too hard in the CSS area and hence has a high contact resistance with the head, resulting in a deteriorated durability.

From such a point of view, it seems effective to
5   make physical properties of the protective film in the CSS area different from those in the data area. It has been proposed to form a protective film composed mainly of diamond in the CSS area and composed mainly of a mixture of graphite and diamond in the data area (JP-A-3-272017).
10 However, when such a protective film is thinned to about 10 nm, it is not sufficient in strength in the CSS area and hence is easily fractured by contact or friction between a magnetic recording medium and a magnetic head at the beginning or end of working.
15   Further, it has been proposed to form a graphite structure in the CSS area and an amorphous structure in the data area (JP-A-4-32021). However, it is clear that a thin film with a graphite structure having a thickness of about 10 nm cannot withstand CSS. Even by combining the
20 technique of JP-B-60-23406 with the techniques of JP-A-3-272017 and JP-A-4-32021, there could not be obtained a magnetic recording medium which had a sufficient strength to withstand its accidental collision with a magnetic head and was free from wear and fracture of its protective film
25 in the CSS area by contact or friction between the magnetic recording medium and the magnetic head at the beginning or end of working even if the thickness of the protective film in the data area was adjusted to about 10 nm or less.

In addition, when a protective film composed of a portion having properties suitable for the CSS area and a portion having properties suitable for the data area is formed by a sputtering method, or when the thickness of a
5   protective film is increased only in the CSS area by a sputtering method, even the formation of the protective film in the data area by the use of, for example, a masking shield out of contact with a magnetic recording medium can limit, only to a certain extent, sputtering particles which
10 pass around behind the masking shield and intrude the data area, because of properties of sputtering. Thus, it has been difficult to make film properties in the CSS area strikingly different from those in the data area or change the film thickness markedly in a short distance.

15   Ion beam deposition is known as a means for forming a protective filmy layer which is tough even at a film thickness smaller than that of a protective filmy layer composed mainly of carbon by sputtering. However, it is industrially difficult to form a protective filmy layer
20 only by ion beam deposition because the life of a hot filament used in an ion gun is short.

SUMMARY OF THE INVENTION

       The present invention was made in view of such problems. A first object of the present invention is to
25 provide a magnetic recording medium which has a sufficient impact resistance to withstand its accidental collision with a magnetic head and is free from wear and fracture of

its protective film in the CSS area by contact or friction
between the magnetic recording medium and the magnetic head
at the beginning or end of working even if the thickness of
the protective film in the data area is reduced to about 10
5 nm or less.

A second object of the present invention is to
provide a process for producing a magnetic recording medium
capable of achieving the first object. A third object of
the present invention is to provide a magnetic storage
10 suitable for attaining both a high packing density and a
high reliability by using a magnetic recording medium
obtained by achieving the above first object.

A fourth object of the present invention is to
provide a process for producing a magnetic recording medium
15 comprising a substrate, a magnetic film formed thereon and
a protective film formed thereon for the protection of said
magnetic film and composed mainly of carbon, said magnetic
recording medium having sufficient impact resistance and
lifting stability in the data area and a sufficient
20 reliability on resistance to sliding in the CSS area, which
process uses both an ion beam deposition method and a
sputtering method.

A fifth object of the present invention is to
provide a magnetic recording medium obtained as a result of
25 achieving the fourth object. A sixth object of the present
invention is to provide a magnetic storage suitable for
attaining both a high packing density and a high relia-
bility by using a magnetic recording medium obtained by

achieving the above fifth object.

For solving the problems described above, the present invention employs the following constitutions:

A magnetic recording medium comprising a
5 substrate, a magnetic film formed thereon and a protective film formed thereon for the protection of said magnetic film and composed mainly of carbon, wherein

a portion of said protective film where said protective film comes into contact with a magnetic head at
10 the time of starting and/or standing of said magnetic head is composed mainly of carbon and nitrogen, and

the portion other than said contact portion of said protective film is composed mainly of not only carbon and nitrogen but also hydrogen for increasing the hardness
15 of the protective film;

A magnetic recording medium comprising a substrate, a magnetic film formed thereon and a protective film formed thereon for the protection of said magnetic film and composed mainly of carbon, wherein

20 the hardness of a portion of said protective film where said protective film comes into contact with a magnetic head at the time of starting and/or standing of said magnetic head is less than 19 Gpa and not less than 15 Gpa, and

25 the hardness of the portion other than said contact portion of said protective film is 19 Gpa or more;

A magnetic recording medium comprising a substrate, a magnetic film formed thereon and a protective

film formed thereon for the protection of said magnetic
film and composed mainly of carbon, wherein

a portion of said protective film where said
protective film comes into contact with a magnetic head at
5 the time of starting and/or standing of said magnetic head
is composed mainly of carbon and nitrogen and has a hard-
ness of less than 19 Gpa and not less than 15 Gpa, and

the portion other than said contact portion of
said protective film is composed mainly of carbon, nitrogen
10 and hydrogen and has a hardness of 19 Gpa or more;

The above-mentioned magnetic recording medium
wherein

the thickness of the portion other than said
contact portion of said protective film is 15 nm or less;
15 A process for producing a magnetic recording
medium comprising a substrate, a magnetic film formed
thereon and a protective film formed thereon for the
protection of said magnetic film and composed mainly of
carbon, which comprises
20 forming a protective filmy layer capable of
constituting substantially the whole surface of said
magnetic recording medium, by a sputtering method using H_2
in addition to either only N_2 or a combination of N_2 and at
least one of Ne, Ar, Kr and Xe, and then
25 forming another protective filmy layer thereon as
a portion of said protective film where the protective film
comes into contact with a magnetic head at the time of
starting and/or standing of said magnetic head, by a

sputtering method using either only N_2 or a combination of N_2 and at least one of Ne, Ar, Kr and X, after taking a means for preventing the adhesion of sputtering particles in the portion other than said contact portion;

5   A process for producing a magnetic recording medium comprising a substrate, a magnetic film formed thereon and a protective film formed thereon for the protection of said magnetic film and composed mainly of carbon, which comprises

10   forming a filmy layer as a portion of said protective film where said protective film comes into contact with a magnetic head at the time of starting or standing of said magnetic head, by an ion beam method using either only a hydrocarbon gas or a combination of a hydro-

15 carbon gas and at least one of Ne, Ar, Kr and Xe, and then

forming another protective filmy layer capable of constituting substantially the whole surface of said magnetic recording medium, by a physical vapor deposition method or a chemical vapor deposition method;

20   A process for producing a magnetic recording medium comprising a substrate, a magnetic film formed thereon and a protective film formed thereon for the protection of said magnetic film and composed mainly of carbon, which comprises

25   forming a protective filmy layer capable of constituting substantially the whole surface of said magnetic recording medium, by a physical vapor deposition method or a chemical vapor deposition method, and then

forming another filmy layer thereon as a portion
of said protective film where said protective film comes
into contact with a magnetic head at the time of starting
or standing of said magnetic head, by an ion beam method
5 using either only a hydrocarbon gas or a combination of a
hydrocarbon gas and at least one of Ne, Ar, Kr and Xe; and

A magnetic recording medium comprising a
substrate, a magnetic film formed thereon and a protective
film formed thereon for the protection of said magnetic
10 film and composed mainly of carbon, wherein

a portion of said protective film where said
protective film comes into contact with a magnetic head at
the time of starting or standing of said magnetic head
comprises a diamond-like (DLC) layer composed mainly of
15 carbon and hydrogen and an amorphous carbon layer composed
mainly of carbon, a combination of carbon and nitrogen, or
a combination of carbon, nitrogen and hydrogen, and

the portion other than said contact portion of
said protective film comprises an amorphous carbon layer
20 composed mainly of carbon, a combination of carbon and
nitrogen, or a combination of carbon, nitrogen and
hydrogen.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic cross-sectional view of a
25 magnetic recording medium according to one embodiment of
the present invention.

Fig. 2 is a schematic illustration of a

protective-film forming chamber 21.

Fig. 3 is a schematic illustration of a protective-film forming chamber 22.

Fig. 4 is a diagram showing the whole structure of a magnetic storage.

Fig. 5 is a schematic perspective view of a magnetic head.

Fig. 6 is a diagram showing the structure of a section of a magnetoresistance sensor.

Fig. 7 is a cross-sectional view of a sensor using a spin valve type magnetic head.

Fig. 8A, Fig. 8B and Fig. 8C are schematic cross-sectional views of a magnetic recording medium according to another embodiment of the present invention.

Fig. 9 is a schematic illustration of a protective-film forming chamber 21'.

Fig. 10 is a schematic illustration of a protective-film forming chamber 31'.

Fig. 11 is a spectrum showing the results of Raman spectroscopic analysis of a protective filmy layer formed by an ion beam deposition method according to further another embodiment of the present invention.

Fig. 12 is a spectrum showing the results of Raman spectroscopic analysis of a protective filmy layer formed by a sputtering method according to still another embodiment of the present invention.

Fig. 13 is a schematic illustration of a protective-film forming chamber 21' for forming a film on

the periphery side of a magnetic recording medium.

In the drawings, the reference numerals denote the following:

1:    nonmagnetic substrate,

5   2:   Cr alloy primer layer,

3:    Co alloy magnetic layer,

4:    protective filmy layer,

5:    protective filmy layer,

21:   protective-film forming chamber,

10   22:   protective-film forming chamber,

23:   shield against sputtering particles,

24:   shield against sputtering particles,

61:   magnetic disc medium,

62:   driving unit for driving a magnetic recording

15   medium,

63:   magnetic head comprising a recording portion and a
reproducing portion,

64:   means for moving the magnetic head in relation to
the aforesaid magnetic recording medium,

20   65:   means for inputting signals into the magnetic head,
and a record reproduction signal processing means
for reproducing outputted signals,

601: base,

602: coil,

25   603: upper recording magnetic pole,

604: lower recording magnetic pole and upper shielding
layer,

605: magnetoresistance sensor,

606: electrode pattern on each side of the magneto-resistance sensor,

607: lower shield layer,

608: gap layer,

5 700: gap layer of aluminum oxide,

701: signal detection region of a magnetism sensor,

702: lateral-bias layer,

703: separating layer for preventing the diversion of a sense electric current,

10 704: magnetoresistance ferromagnetic layer,

705: tapered portion formed by tapering,

706: permanent-magnet layer,

801: Ta buffer layer,

802: first magnetic layer,

15 803: nonmagnetic intermediate layer made of copper,

804: second magnetic layer,

805: antiferromagnetic alloy layer,

1': nonmagnetic substrate,

2': Cr alloy primer layer,

20 3': Co alloy magnetic layer,

4': protective filmy layer,

5': protective filmy layer,

21': protective-film forming chamber,

22': hot filament,

25 23': anode,

24': grid,

25': shield against deposited particles,

31': protective-film forming chamber.

DETAILED DESCRIPTION OF THE INVENTION

First, the outlines of the constitution, function and action of the present invention are explained below. In a magnetic disc comprising a substrate, a magnetic film

5 formed thereon and a protective film formed thereon for the protection of said magnetic film and composed mainly of carbon, a portion of said protective film where a magnetic head comes into contact with said protective film at the time of starting and/or standing of the magnetic head is

10 composed mainly of carbon and nitrogen, and the other portion of said protective film is composed mainly of not only carbon and nitrogen but also hydrogen as an adjusting means for changing film properties (hardness and Young's modulus).

15 When the hardness of the portion of said protective film where a magnetic head comes into contact with said protective film at the time of starting and/or standing of the magnetic head is measured in a definite-indentation-depth mode by using a Barkovich type diamond

20 indenter having a radius of curvature of 0.1 μm, it is preferably less than 19 Gpa and not less than 15 Gpa at an indentation depth of 10 nm. The hardness of the other portion of said protective film than the portion where a magnetic head comes into contact with said protective film

25 at the time of starting and/or standing of the magnetic head is preferably 19 Gpa or more. The thickness of the other portion of said protective film than the portion where a magnetic head comes into contact with said

protective film at the time of starting and/or standing of the magnetic head is preferably 10 nm or less.

The reason why the hardness of the portion of said protective film where a magnetic head comes into
5 contact with said protective film at the time of starting and/or standing of the magnetic head is preferably less than 19 Gpa and not less than 15 Gpa is that the protective film is liable to be worn away when the hardness is less than 15 Gpa, and that the protective film is liable to be
10 fractured by shear stress due to sliding on the head when the hardness is more than 19 Gpa. The reason why the hardness of the other portion of said protective film than the portion where a magnetic head comes into contact with said protective film at the time of starting and/or
15 standing of the magnetic head is preferably 19 Gpa or more is that at a hardness of less than 19 Gpa, said protective film tends to be injured, resulting in crash, if the magnetic head at work collides with the protective film accidentally or any substance is present between the
20 magnetic head and said protective film.

The reason why the thickness of the other portion of said protective film than the portion where a magnetic head comes into contact with said protective film at the time of starting and/or standing of the magnetic head is
25 preferably 10 nm or less is that the distance between the magnetic head and the magnetic recording layer is too long when the thickness is more than 10 nm.

The above-mentioned protective film can be

obtained by forming a film composed mainly of carbon,
hydrogen and nitrogen and laminating another film composed
mainly of carbon and nitrogen on the film composed mainly
of carbon, hydrogen and nitrogen, as the portion of the
5 protective film where a magnetic head comes into contact
with the protective film at the time of starting and/or
standing of the magnetic head. Such a protective film can
be formed by forming a film by a sputtering method using a
carbon graphite target and using H_2 in addition to either
10 only N_2 or a combination of N_2 and at least one of inactive
gases Ne, Ar, Kr and Xe, and then forming another film
thereon by a sputtering method using a carbon graphite
target and using either only N_2 or a combination of N_2 and
at least one of Ne, Ar, Kr and Xe, after taking a means (a
15 combination of a mask and an anode) for preventing the
adhesion of sputtering particles in the portion other than
a portion where a magnetic head comes into contact with the
protective film at the time of starting and/or standing of
the magnetic head.

20   The magnetic storage of the present invention can
be obtained as a magnetic storage comprising a magnetic
recording medium, a driving unit for driving said magnetic
recording medium, a magnetic head comprising a recording
portion and a reproducing portion, a means for moving said
25 magnetic head in relation to said magnetic recording
medium, a means for inputting signals into said magnetic
head, and a record reproduction signal processing means for
reproducing signals outputted from said magnetic head,

wherein the reproducing portion of the magnetic head is composed of a magnetoresistance effect type magnetic head, and the magnetic recording medium is composed of a magnetic recording medium comprising a protective film having film properties, hardness and thickness which have the characteristics described above.

Further, the magnetoresistance sensor portion of said magnetoresistance effect type magnetic head is formed between two shield layers made of a soft magnetic material which are at a distance of 0.2 μm or less from each other. In addition, the product of the thickness t of magnetic layer of the magnetic recording medium having the structure described above and the residual magnetic flux density Br measured by applying a magnetic field in a direction of traveling of said magnetic head in relation to said magnetic recording medium during recording, i.e., Br × t is adjusted to not more than 9.6 mA (120 gauss · micron) and not less than 3.2 mA (40 gauss · micron).

The reason why the magnetoresistance sensor portion of said magnetoresistance effect type magnetic head has to be formed between two shield layers made of a soft magnetic material which are at a distance of 0.2 μm or less from each other is that otherwise no sufficient reproduction output can be attained in a magnetic storage having a maximum line packing density of more than 220 kFCI. The distance between the two shield layers made of a soft magnetic material is preferably 0.12 μm or more from the viewpoint of ease of construction.

The reason why the product of the thickness t of magnetic layer of the magnetic recording medium having the structure described above and the residual magnetic flux density Br measured by applying a magnetic field in a direction of traveling of said magnetic head in relation to said magnetic recording medium during recording, i.e., Br × t is not more than 9.6 mA (120 gauss·micron) and not less than 3.2 mA (40 gauss·micron) is as follows: when Br × t is less than 3.2 mA (40 gauss·micron), inaccurate information is very likely to be reproduced owing to a decrease of the reproduction output caused by long-term standing after recording; and when Br × t is more than 9.6 mA (120 gauss·micron), overwriting at the time of recording becomes difficult.

In addition, it is also possible to control the crystalline orientation of the magnetic layer by forming a primer layer composed of at least two layers in said magnetic recording medium. By forming this multi-layer primer layer, the influence of diffusion of atoms from the primer layer to the magnetic layer can be greatly reduced, and at the same time, the crystallinity of the primer layer adjacent to the magnetic layer can be improved, so that the adhesion between the magnetic layer and the primer layer is increased, resulting in a high resistance to sliding. Furthermore, since the surface of the primer layer adjacent to the magnetic layer has no long-range periodic atom alignment, grains of the magnetic layer formed on the primer layer can be refined and the crystalline orientation

of the magnetic layer becomes contollable. Accordingly,
the average grain size of crystals constituting the
magnetic layer can be controlled to a very small size of 15
nm or less suitable for noise reduction, and at the same
5 time, the direction of the axis of easy magnetization can
be controlled to a direction parallel to the film surface
which is suitable for in-plane magnetic recording.

The magnetoresistance effect type magnetic head
used in the magnetic storage of the present invention
10 comprises a magnetoresistance sensor comprising a plurality
of electroconductive magnetic layers capable of causing a
great resistance change owing to relative changes of their
mutual directions of magnetization which are caused by an
external magnetic field, and electroconductive nonmagnetic
15 layers located among said electroconductive magnetic
layers. Such a reproducing head is used in order to
reproduce stably signals recorded at a maximum line packing
density of more than 300 kFCI, to obtain a signal output.

Further, the present invention is accomplished by
20 forming the magnetoresistance effect type magnetic head on
a magnetic head slider having an area of a lifting surface
rail of 1.25 mm^2 or less and a mass of 2 mg or less. The
reason why the area of the lifting surface rail is 1.25 mm^2
or less is that the probability of collision with the
25 above-mentioned projections is reduced and that at the same
time the reliability on impact resistance can be improved
by adjusting the mass to 2 mg or less. Thus, it becomes
possible to attain both a packing density of 5 gigabits or

more per square inch and a high reliability on impact
resistance.

        In a magnetic recording medium comprising a
substrate, a magnetic film formed thereon and a protective

5 film formed thereon for the protection of said magnetic
film and composed mainly of carbon, the following is also
possible: a portion of said protective film where said
protective film comes into contact with a magnetic head at
the time of starting and/or standing of said magnetic head

10 is formed of a diamond-like (DLC) layer composed mainly of
carbon and hydrogen and an amorphous carbon layer composed
mainly of carbon and nitrogen and containing hydrogen, and
the portion other than said contact portion of said
protective film is formed of an amorphous carbon layer

15 composed mainly of carbon and nitrogen and containing
hydrogen.

        The reason why the contact portion of said
protective film is formed of a diamond-like (DLC) layer
composed mainly of carbon and hydrogen and an amorphous

20 carbon layer composed mainly of carbon and nitrogen and
containing hydrogen is that imparting thereto a sufficient
strength to prevent fracture by sliding on the magnetic
head during CSS is aimed at. The reason why the portion
other than said contact portion of said protective film is

25 formed of an amorphous carbon layer composed mainly of
carbon and nitrogen and containing hydrogen is that
imparting thereto a sufficient strength to withstand
collision with the magnetic head is aimed at.

In addition, the thickness of the other portion
of said protective film than the portion where said
protective film comes into contact with a magnetic head at
the time of starting and/or standing of said magnetic head
5   is preferably 10 nm or less. The thickness of the portion
of said protective film where said protective film comes
into contact with a magnetic head at the time of starting
and/or standing of said magnetic head is preferably larger
than that of the portion other than said contact portion of
10 said protective film and is preferably 20 nm or less. The
rate of thickness change in the radial direction of said
protective film in the boundary between said contact
portion of said protective film and the portion other than
said contact portion of said protective film is preferably
15 higher than the rate of thickness change in the radial
direction in the portion other than said contact portion of
said protective film and has a value of preferably 1.0
nm/mm or more.

The reason why the thickness of the other portion
20 of said protective film than the portion where said protec-
tive film comes into contact with a magnetic head at the
time of starting and/or standing of said magnetic head is
preferably 10 nm or less is that when the thickness is more
than 10 nm, the distance between the magnetic head and the
25 magnetic recording layer is large and hence not suitable
for a high packing density. The reason why the thickness
of the portion of said protective film where said protec-
tive film comes into contact with a magnetic head at the

time of starting and/or standing of said magnetic head is
preferably larger than that of the portion other than said
contact portion of said protective film and is preferably
20 nm or less is that when the thickness is more than 20

5   nm, a sufficient strength is imparted but the attitude of
said magnetic head is not stable at the time of its
starting, resulting in an increased possibility of the
contact of the magnetic head with said magnetic recording
medium.

10   The reason why the rate of thickness change in
the radial direction of said protective film in the
boundary between said contact portion of said protective
film and the portion other than said contact portion of
said protective film is preferably higher than the rate of

15   thickness change in the radial direction in the portion
other than said contact portion of said protective film and
has a value of preferably 1.0 nm/mm or more is that the
following purpose is achieved: the thickness of the portion
of said protective film where said protective film comes

20   into contact with a magnetic head at the time of starting
and/or standing of said magnetic head is increased in a
short distance as abruptly as possible, whereby the
uniformity of film thickness in the data area is assured
and the thickness of the portion of said protective film

25   where said protective film comes into contact with a
magnetic head at the time of starting and/or standing of
said magnetic head is assured as desired.

          Such a protective film as is described above can

be produced either by forming a filmy layer as a portion of said protective film where said protective film comes into contact with a magnetic head at the time of starting and/or standing of said magnetic head, by an ion beam method using

5   either only a hydrocarbon gas or a combination of a hydrocarbon gas and at least one of Ne, Ar, Kr and Xe, and then forming another protective filmy layer capable of constituting substantially the whole surface of the above-mentioned magnetic recording medium, by a sputtering method

10 using N_2 and at least one of H_2, Ne, Ar, Kr and Xe; or by forming a protective filmy layer capable of constituting substantially the whole surface of the above-mentioned magnetic recording medium, by a sputtering method using N_2 and at least one element of H_2, Ne, Ar, Kr and Xe, and then

15 forming another filmy layer thereon as a portion of said protective film where said protective film comes into contact with a magnetic head at the time of starting and/or standing of said magnetic head, by an ion beam method using either only a hydrocarbon gas or a combination of a hydro-

20 carbon gas and at least one element of Ne, Ar, Kr and Xe. In forming a filmy layer as said contact portion by the ion beam method, it is effective to take a means for preventing the formation of a filmy layer as the portion other than said contact portion by placing a shield in the vicinity of

25 the above-mentioned magnetic recording medium.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention are

explained below in detail. Fig. 1 shows one example of embodiment of the present invention.

Embodiment 1

5   A substrate 1 obtained by plating an aluminum alloy base material (outside diameter 95 mm, inside diameter 25 mm, thickness 0.8 mm) with Ni-P was textured so that Ra = 2 nm and Rp = 15 nm (Ra and Rp are indications of roughness). Then, projections having a height of 15 nm and a diameter of 3.5 μm were formed thereon at intervals of 10 10 μm by laser irradiation in the area corresponding to a disc radius R range of 18 to 20.7 mm and the thus treated substrate 1 was thoroughly washed. The substrate 1 was introduced into a vacuum tank evacuated to about 5.3 × 10 E - 5 Pa (4.0 × 10 E - 7 Torr). First, the substrate 1 was 15   conveyed to a heating chamber in the vacuum tank and heated to 260°C with an IR heater (infrared heater).

Subsequently, the substrate 1 was conveyed to a primer-layer forming chamber and a Cr-10 at.% Mo-7.5 at.% Ti alloy primer layer 2 was formed thereon in a thickness 20   of 30 nm by a DC magnetron sputtering method under an Ar atmosphere at about 0.8 Pa (6 mTorr). Then, the substrate 1 was conveyed to a magnetic-recording-layer forming chamber and a Co-20 at.% Cr-4 at.% Ta-8 at.% Pt alloy layer 3 (capable of forming a magnetic layer) was formed thereon 25   in a thickness of 22 nm by a DC magnetron sputtering method under an Ar atmosphere at about 0.9 Pa (7 mTorr). Using this substrate having the Cr-10 at.% Mo-7.5 at.% Ti alloy

primer layer 2 and Co-20 at.% Cr-4 at.% Ta-8 at.% Pt alloy layer 3 formed thereon, the following protective filmy layers composed mainly of carbon according to the present invention were formed.

5   As the above-mentioned substrate 1, there can be used, for example, rigid substrates made of ceramics of chemically strengthened aluminosilicate, soda-lime glass, silicon, borosilicate glass, etc. or made of glass-glazed ceramics, as well as Al-Mg alloy substrates subjected to

10   nonelectrode plating with Ni-P.

The primer layer 2 is used as a primer film for controlling the crystalline orientation of the magnetic layer formed thereon. As the primer layer, there can also be used thin films of Cr-based alloys such as nonmagnetic

15   Cr-V, Cr-Ti, Cr-Mo, Cr-Si and Cr-Mo-Ti alloys which form disordered solid solutions capable of being subjected to (100) orientation good in crystal matching with the magnetic film. When the primer layer was formed by adding 0.5 vol% to 50 vol% of nitrogen to a gas for discharge used

20   in the sputtering, the refinement of grains of the primer layer took place. Consequently, grains of the magnetic layer subsequently formed were also refined, so that medium noise could be reduced.

As the magnetic layer 3, there can be used not

25   only Co-Cr-Pt-Ta alloys but also multi-component alloy systems which are composed mainly of Co, contain Pt for increasing the coercive force and contain Cr, Ta, SiO_2, Nb, etc. for reducing medium noise. Particularly when Ta, Nb,

V or Ti was added, the melting point of a target was lowered, so that the progress of component separation of the magnetic film containing Cr was desirably facilitated.

Co-based alloy systems containing Pt, Ni or Mn
5 are practical because their anisotropy energy does not decrease so much as that of Co-based alloy systems containing any other additive element. Specifically, there can be used alloys such as Co-Cr-Pt-Ta, Co-Cr-Pt-SiO$_2$, Co-Cr-Pt-Mn, Co-Cr-Nb-Pt, Co-Cr-V-Pt, Co-Cr-Ti-Pt, Co-Cr-Nb-Ta-Pt,
10 Co-Pt-Ni-SiO$_2$, etc., as well as Co-Cr-Pt.

As to the composition of the Co alloy layer constituting the ferromagnetic portion, the amount of Cr incorporated as a solid solution is considered to be 5 to 10 at.% and the amount of Ta incorporated as a solid
15 solution about 2 at.%. When the Co alloy magnetic layer is formed by incorporating Cr and Ta in amounts larger than the above amounts, magnetic separation in the magnetic layer proceeds, resulting in reduced medium noise. As a practical composition, there can be used, for example,
20 Co-20 at.% Cr-4 at.% Ta-8 at.% Pt alloy,
Co-22 at.% Cr-20 at.% Pt alloy,
Co-15 at.% Cr-8 at.% Pt-20 mol.% SiO$_2$ alloy,
Co-17 at.% Cr-12 at.% Pt-5 at.% Mn alloy,
Co-17 at.% Cr-5 at.% Nb-10 at.% Pt alloy,
25 Co-20 at.% Cr-5 at.% V-12 at.% Pt alloy,
Co-20 at.% Cr-10 at.% V-15 at.% Pt alloy, and
Co-15 at.% Cr-5 at.% Nb-5 at.% Ta-20 at.% Pt alloy.

The above-mentioned substrate was conveyed to the

protective-filmy-layer forming chamber 21 shown in Fig. 2
without taking out the substrate from the vacuum tank. Ar
gas containing 30% N_2 and 7.5% H_2 was introduced into the
chamber 21 at a rate of 24 sccm (Standard cubic centimeter
5   per minute) through a mass flow controller while evacuating
the protective-filmy-layer forming chamber 21 with a turbo
molecular pump. In this case, the pressure was about 1 Pa
(8 mTorr) as measured with a Baratron gauge. Then, DC 1000
W was applied to graphite sintering targets fixed on
10 cathodes located on both sides of the substrate, to induce
plasma. In this case, the discharge current was about 1.5
A and the discharge voltage about 670 V.

By this so-called reactive sputtering method, a
protective filmy layer 4 composed mainly of carbon and
15 containing large amounts of nitrogen and hydrogen was
formed in a thickness of 8 nm on the Co-Cr-Ta-Pt alloy
layer 3. In this case, the build-up rate of the film was
0.8 nm/s.

Next, the thus treated substrate was conveyed to
20 a protective-filmy-layer forming chamber 22. The
protective-filmy-layer forming chamber 22 is equipped with
the shields against sputtering particles 23 and 24 shown in
Fig. 3, so as to have such a structure that a film is
actively built up only in the whole area within a disc
25 radius of 20.7 mm on the substrate where a magnetic head
comes into contact with a protective film to be formed, at
the time of starting and/or standing of the magnetic head
and that build-up of a film is very difficult outside a

disc radius of 20.7 mm. Ar gas containing 30% N_2 was
introduced into the chamber 22 at a rate of 15 sccm through
a mass flow controller while evacuating the protective-
filmy-layer forming chamber 22 with a turbo molecular pump.
5 In this case, the pressure was about 0.9 Pa (6.5 mTorr) as
measured with a Baratron gauge.

       Then, DC 1000 W was applied to graphite sintering
targets fixed on cathodes located on both sides of the
substrate, to induce plasma. In this case, the discharge
10 current was about 1.4 A and the discharge voltage about 710
V. By this so-called reactive sputtering method, a protec-
tive filmy layer 5 composed mainly of carbon and containing
a large amount of nitrogen was formed in a thickness of 5
nm within a disc radius of 20.7 mm on the protective filmy
15 layer 4. In this case, the build-up rate of the film was
0.5 nm/s. The thus treated substrate was taken out of the
vacuum tank and allowed to cool to room temperature
spontaneously.

       A plurality of discs were produced in the manner
20 described above. Some of them were used for analyzing
their protective filmy layers. Some others were subjected
to tape cleaning and then provided with a layer of about 2
nm thick of a fluorocarbon type lubricant, and after lift-
ing check, they were subjected to a sliding test singly or
25 subjected to a reliability test after being incorporated
into a magnetic disc apparatus.

       The protective film of the disc produced in the
manner described above was analyzed at an angle of

detection of 30° by X-ray photoelectron spectroscopy (ESCA).
As a result, the following was found: at a radial position
of 19 mm and in a depth range of 0 nm to about 3 nm from
the surface, the proportion of carbon atoms was 75 at.%,
5   the proportion of nitrogen atoms was 15 at.% and the
balance was of other atoms including mainly oxygen. The
following was also found: at a radial position of 30 mm and
in a depth range of 0 nm to about 3 nm from the surface,
the proportion of carbon atoms was 77 at.%, the proportion
10   of nitrogen atoms was 17 at.% and the balance was of other
atoms including mainly oxygen. Thus, the amount of
nitrogen in the protective filmy layer 4 and that in the
protective filmy layer 5 were not widely different.

          The protective film was subjected to hydrogen
15   forward scattering spectroscopy (HFS) under the following
conditions: He + +ion beam energy = 160 fJ (1 MeV); angle
of detection 30°. It was also subjected to Rutherford
backscattering spectroscopy (RBS) at an angle of detection
of 160°. As a result, it was found that the percentage of
20   the number of hydrogen atoms based on the total number of
carbon atoms and hydrogen atoms was 8% at a radial position
of 19 mm and 23% at a radial position of 30 mm, namely, the
protective filmy layer 4 contained a large number of
hydrogen atoms, while the protective filmy layer 5 did not
25   contain a large number of hydrogen atoms.

          Then, the hardness and Young's modulus of the
protective film were estimated at radial positions of 19 mm
(CSS area) and 30 mm (data area). The hardness and Young's

modulus referred to here are those measured with a thin-film microhardness measuring apparatus (a nanoindenter) manufactured by Nano Instrument Co., in a definite-indentation-depth mode by using a Barkovich type diamond

5   indenter having a radius of curvature of 0.1 μm. As a result, it was found that at a radial position of 19 mm and a depth of 5 nm, the hardness was 17 GPa and the Young's modulus 216 GPa, and that at a radial position of 30 mm and a depth of 5 nm, the hardness was 21 GPa and the Young's

10 modulus 241 GPa. Thus, the protective filmy layer 4 had both a larger hardness value and a larger Young's modulus value than did the protective filmy layer 5.

On the other hand, ten of the discs also having the lubricant layer formed thereon were individually set in

15 a contact-start-and-stop (CSS) evaluation apparatus and tested. When the 10 discs were subjected to CSS 50,000 times at a revolution rate of 7,500 r.p.m., all of the 10 discs finished the test without crash. When their surfaces after the test were carefully observed under a microscope

20 and carefully and visually observed by oblique light, no injury was detected in the discs. Thus, it was proved that the magnetic recording medium of the present invention has a sufficient reliability on resistance to sliding when the thickness of the protective film in the CSS area is 13 nm.

25   Next, 0.1 g of alumina particles having an average particle size of 0.1 μm were casted on each of the 10 discs while carrying out random seeking of a magnetic head at 7,500 r.p.m. in the area other than the area where

CSS was carried out, i.e., the so-called data area
(corresponding to a disc radius range of 21 mm to 46 mm)
where the protective film did not steadily come into
contact with the magnetic head. After 120 seconds of the
5   seeking, the disc surface was observed under a microscope
and visually observed by oblique light. As a result, it
was found that although the surface of the protective film
had received some very slight scratches, so-called crash
accompanying the fracture of the protective film had not
10 occurred. Thus, it was proved that the magnetic recording
medium of the present invention can have a sufficient
reliability on resistance to sliding though the thickness
of the protective filmy layer in the data area is as very
small as 8 nm. The above evaluation results are described
15 in Table 1 as those for sample No. 1.

Comparative Example 1
            Sample No. 2 was produced by substantially the
same process as in Embodiment 1 except that no protective
filmy layer 5 was formed. Sample No. 2 was evaluated by
20 the same methods as in Embodiment 1. As a result of ESCA
analysis, the following was found: at a radial position of
19 mm and in a depth range of 0 nm to about 3 nm from the
surface, the proportion of carbon atoms was 75 at.%, the
proportion of nitrogen atoms was 15 at.% and the balance
25 was of other atoms.
            The following was also found: at a radial
position of 30 mm and in a depth range of 0 nm to about 3

nm from the surface, the proportion of carbon atoms was 77
at.%, the proportion of nitrogen atoms was 17 at.% and the
balance was of other atoms including mainly oxygen. Thus,
there was no significant difference between the results
5   obtained at the radial position of 19 mm and the results
obtained at the radial position of 30 mm. As a result of
HFS and RBS analyses, it was found that the percentage of
the number of hydrogen atoms based on the total number of
carbon atoms and hydrogen atoms was 22% at a radial
10 position of 19 mm and 25% at a radial position of 30 mm,
namely, it was not significantly different at the two
radial positions. At a radial position of 19 mm and a
depth of 5 nm, the hardness was 20 GPa and the Young's
modulus 240 GPa. At a radial position of 30 mm and a depth
15 of 5 nm, the hardness was 20 GPa and the Young's modulus
243 GPa. Thus, the hardness and the Young's modulus were
not significantly different at the two radial positions.

On the other hand, 10 discs also having a
lubricant layer formed thereon were individually set in a
20 (CSS) evaluation apparatus and tested in the same manner as
in Embodiment 1. As a result, all of the 10 discs under-
went crash owing to less than 1,000 runs of CSS. In
addition, 10 other discs also having a lubricant layer
formed thereon were subjected to a seek test and surface
25 observation in the same manner as in Embodiment 1.
Although the surface of the protective film of each disc
received some very slight scratches, so-called crash
accompanying the fracture of the protective film did not

occur. Thus, it turned out that sample No. 2 produced by
the process according to Comparative Example 1 has a
sufficient reliability on resistance to sliding in the data
area but cannot have a sufficient reliability on resistance
5 to sliding in the CSS area.

Comparative Example 2

When a protective filmy layer 5 was formed in the
protective-filmy-layer forming chamber 22, pure Ar gas was
introduced into the chamber 22 at a rate of 15 sccm through
10 a mass flow controller. In this case, the pressure was
about 0.9 Pa (6.8 mTorr) as measured with a Baratron gauge.
Then, DC 1000 W was applied to graphite sintering targets
fixed on cathodes located on both sides of the substrate,
to induce plasma. In this case, the discharge current was
15 about 1.6 A and the discharge voltage about 625 V. By this
sputtering method, the protective filmy layer 5 composed
mainly of carbon was formed in a thickness of 5 nm within a
disc radius of 20.7 mm on a protective filmy layer 4. In
this case, the build-up rate of the film was 0.95 nm/s.
20 Sample No. 3 was produced by substantially the same process
as in Embodiment 1 except for the above method for forming
the protective filmy layer 5.

Sample No. 3 was evaluated by the same methods as
in Embodiment 1. As a result of ESCA analysis, the
25 following was found: at a radial position of 19 mm and in a
depth range of 0 nm to about 3 nm from the surface, the
proportion of carbon atoms was 85 at.%, the proportion of

nitrogen atoms was 5 at.% and the balance was of other
atoms including mainly oxygen.

　　　The following was also found: at a radial
position of 30 mm and in a depth range of 0 nm to about 3
5   nm from the surface, the proportion of carbon atoms was 77
at.%, the proportion of nitrogen atoms was 17 at.% and the
balance was of other atoms including mainly oxygen. As a
result of HFS and RBS analyses, it was found that the
percentage of the number of hydrogen atoms based on the
10 total number of carbon atoms and hydrogen atoms was 7% at a
radial position of 19 mm and 22% at a radial position of 30
mm. At a radial position of 19 mm and a depth of 5 nm, the
hardness was 7 GPa and the Young's modulus 110 GPa. At a
radial position of 30 mm and a depth of 5 nm, the hardness
15 was 21 GPa and the Young's modulus 237 GPa.

　　　On the other hand, 10 discs also having a
lubricant layer formed thereon were individually set in a
(CSS) evaluation apparatus and tested in the same manner as
in Embodiment 1. As a result, all of the 10 discs under-
20 went crash owing to less than 5,000 runs of CSS. In
addition, 10 other discs also having a lubricant layer
formed thereon were subjected to a seek test and surface
observation in the same manner as in Embodiment 1.
Although the surface of the protective film of each disc
25 received some very slight scratches, so-called crash
accompanying the fracture of the protective film did not
occur. Thus, it turned out that sample No. 3 produced by
the process according to Comparative Example 2 has a

sufficient reliability on resistance to sliding in the data
area but cannot have a sufficient reliability on resistance
to sliding in the CSS area.

Comparative Example 3

5   When a protective filmy layer 4 was formed in the
protective-filmy-layer forming chamber 21, Ar gas contain-
ing 30% N_2 was introduced into the chamber 21 at a rate of
24 sccm through a mass flow controller. In this case, the
pressure was about 1.2 Pa (9.0 mTorr) as measured with a

10 Baratron gauge. Then, DC 1000 W was applied to graphite
sintering targets fixed on cathodes located on both sides
of the substrate, to induce plasma. In this case, the
discharge current was about 1.3 A and the discharge voltage
about 770 V. By this so-called reactive sputtering method,

15 the protective filmy layer 4 composed mainly of carbon and
containing a large amount of nitrogen was formed in a
thickness of 8 nm on a Co-Cr-Ta-Pt alloy layer 3.

          In this case, the build-up rate of the film was
1.0 nm/s. Sample No. 4 was produced by substantially the

20 same process as in Embodiment 1 except for the above method
for forming the protective filmy layer 4. Sample No. 4 was
evaluated by the same methods as in Embodiment 1. As a
result of ESCA analysis, the following was found: at a
radial position of 19 mm and in a depth range of 0 nm to

25 about 3 nm from the surface, the proportion of carbon atoms
was 73 at.%, the proportion of nitrogen atoms was 15 at.%
and the balance was of other atoms including mainly oxygen.

The following was also found: at a radial
position of 30 mm and in a depth range of 0 nm to about 3
nm from the surface, the proportion of carbon atoms was 74
at.%, the proportion of nitrogen atoms was 17 at.% and the
5   balance was of other atoms including mainly oxygen. As a
result of HFS and RBS analyses, it was found that the
percentage of the number of hydrogen atoms based on the
total number of carbon atoms and hydrogen atoms was 5% at
radial positions of 19 mm and 30 mm. At a radial position
10 of 19 mm and a depth of 5 nm, the hardness was 16 GPa and
the Young's modulus 212 GPa. At a radial position of 30 mm
and a depth of 5 nm, the hardness was 17 GPa and the
Young's modulus 217 GPa.

On the other hand, 10 discs also having a
15 lubricant layer formed thereon were individually set in a
(CSS) evaluation apparatus and tested in the same manner as
in Embodiment 1. As a result, all of the 10 discs finished
the test without crash, and no injury was detected in the
discs by subsequent surface observation. However, when the
20 10 discs were subjected to a seek test in the same manner
as in Embodiment 1, their protective films received very
slight scratches on the surfaces in about 10 seconds and
were fractured in about 30 seconds, resulting in crash.

Thus, it turned out that sample No. 4 produced by
25 the process according to Comparative Example 3 has a
sufficient reliability on resistance to sliding in the CSS
area but cannot have a sufficient reliability on resistance
to sliding in the data area.

Comparative Example 4

When a protective filmy layer 5 was formed in the protective-filmy-layer forming chamber 22, Ar gas containing 30% N_2 and 7.5% H_2 was introduced into the chamber 22 at

5   a rate of 15 sccm through a mass flow controller. In this case, the pressure was about 0.8 Pa (6.2 mTorr) as measured with a Baratron gauge. Then, DC 1000 W was applied to graphite sintering targets fixed on cathodes located on both sides of the substrate, to induce plasma. In this

10 case, the discharge current was about 1.7 A and the discharge voltage about 590 V.

By this so-called reactive sputtering method, the protective filmy layer 5 composed mainly of carbon and containing large amounts of nitrogen and hydrogen was

15 formed in a thickness of 5 nm within a disc radius of 20.7 mm on a protective filmy layer 4. In this case, the build-up rate of the film was 0.8 nm/s.

Sample No. 5 was produced by substantially the same process as in Embodiment 1 except for the above method

20 for forming the protective filmy layer 5. Sample No. 5 was evaluated by the same methods as in Embodiment 1. As a result of ESCA analysis, the following was found: at a radial position of 19 mm and in a depth range of 0 nm to about 3 nm from the surface, the proportion of carbon atoms

25 was 73 at.%, the proportion of nitrogen atoms was 15 at.% and the balance was of other atoms.

The following was also found: at a radial position of 30 mm and in a depth range of 0 nm to about 3

nm from the surface, the proportion of carbon atoms was 75 at.%, the proportion of nitrogen atoms was 17 at.% and the balance was of other atoms. As a result of HFS and RBS analyses, it was found that the percentage of the number of

5 hydrogen atoms based on the total number of carbon atoms and hydrogen atoms was 25% at radial positions of 19 mm and 30 mm. At a radial position of 19 mm and a depth of 5 nm, the hardness was 22 GPa and the Young's modulus 249 GPa. At a radial position of 30 mm and a depth of 5 nm, the

10 hardness was 20 GPa and the Young's modulus 247 GPa.

On the other hand, 10 discs also having a lubricant layer formed thereon were individually set in a (CSS) evaluation apparatus and tested in the same manner as in Embodiment 1. As a result, all of the 10 discs under-

15 went crash owing to less than 3,000 runs of CSS.

In addition, when 10 other discs also having a lubricant layer formed thereon were subjected to a seek test and surface observation in the same manner as in Embodiment 1, the surface of the protective film of each

20 disc after completion of the test had some very slight scratches though so-called crash accompanying the fracture of the protective film did not occur. Thus, it turned out that sample No. 5 produced by the process according to Comparative Example 4 has a sufficient reliability on

25 resistance to sliding in the data area but cannot have a sufficient reliability on resistance to sliding in the CSS area.

Comparative Example 5

When a protective filmy layer 4 was formed in the protective-filmy-layer forming chamber 21, Ar gas containing no nitrogen was introduced into the chamber 21 at a rate of 24 sccm through a mass flow controller. In this case, the pressure was about 1.3 Pa (9.5 mTorr) as measured with a Baratron gauge. Then, DC 1000 W was applied to graphite sintering targets fixed on cathodes located on both sides of the substrate, to induce plasma. In this case, the discharge current was about 1.6 A and the discharge voltage about 625 V. By this sputtering method, the protective filmy layer 4 composed mainly of carbon was formed in a thickness of 8 nm on a Co-Cr-Ta-Pt alloy layer 3.

In this case, the build-up rate of the film was 0.9 nm/s. Sample No. 6 was produced by substantially the same process as in Embodiment 1 except for the above method for forming the protective filmy layer 4. Sample No. 6 was evaluated by the same methods as in Embodiment 1. As a result of ESCA analysis, the following was found: at a radial position of 19 mm and in a depth range of 0 nm to about 3 nm from the surface, the proportion of carbon atoms was 73 at.%, the proportion of nitrogen atoms was 15 at.% and the balance was of other atoms including mainly oxygen.

The following was also found: at a radial position of 30 mm and in a depth range of 0 nm to about 3 nm from the surface, the proportion of carbon atoms was 85 at.%, the proportion of nitrogen atoms was 6 at.% and the

balance was of other atoms including mainly oxygen. As a result of HFS and RBS analyses, it was found that the percentage of the number of hydrogen atoms based on the total number of carbon atoms and hydrogen atoms was 5% at

5   radial positions of 19 mm and 30 mm. At a radial position of 19 mm and a depth of 5 nm, the hardness was 14 GPa and the Young's modulus 200 GPa. At a radial position of 30 mm and a depth of 5 nm, the hardness was 6 GPa and the Young's modulus 105 GPa.

10   On the other hand, 10 discs also having a lubricant layer formed thereon were individually set in a (CSS) evaluation apparatus and tested in the same manner as in Embodiment 1. As a result, six of the 10 discs could clear 50,000 runs of CSS but the protective films of all

15 the six discs after completion of the test were injured. The other four discs underwent crash owing to 20,000 to 30,000 runs of CSS. In addition, when 10 other discs also having a lubricant layer formed thereon were subjected to a seek test in the same manner as in Embodiment 1, all of

20 these 10 discs underwent crash immediately owing to 3,000 or less revolutions.

Comparative Example 6

          When a protective filmy layer 4 was formed in the protective-filmy-layer forming chamber 21, Ar gas contain-

25 ing 30% N_2 and 15% H_2 was introduced into the chamber 21 at a rate of 24 sccm through a mass flow controller. In this case, the pressure was about 1 Pa (8.0 mTorr) as measured

with a Baratron gauge. Then, DC 1000 W was applied to
graphite sintering targets fixed on cathodes located on
both sides of the substrate, to induce plasma. In this
case, the discharge current was about 1.7 A and the
5   discharge voltage about 590 V. By this so-called reactive
sputtering method, the protective filmy layer 4 composed
mainly of carbon and containing large amounts of nitrogen
and hydrogen was formed in a thickness of 8 nm on a Co-Cr-
Ta-Pt alloy layer 3. In this case, the build-up rate of
10 the film was 0.9 nm/s.

Sample No. 7 was produced by substantially the
same process as in Embodiment 1 except for the above method
for forming the protective filmy layer 4. Sample No. 7 was
evaluated by the same methods as in Embodiment 1. As a
15 result of ESCA analysis, the following was found: at a
radial position of 19 mm and in a depth range of 0 nm to
about 3 nm from the surface, the proportion of carbon atoms
was 73 at.%, the proportion of nitrogen atoms was 16 at.%
and the balance was of other atoms including mainly oxygen.
20 The following was also found: at a radial position of 30 mm
and in a depth range of 0 nm to about 3 nm from the
surface, the proportion of carbon atoms was 74 at.%, the
proportion of nitrogen atoms was 17 at.% and the balance
was of other atoms including mainly oxygen. As a result of
25 HFS and RBS analyses, it was found that the percentage of
the number of hydrogen atoms based on the total number of
carbon atoms and hydrogen atoms was 5% at a radial position
of 19 mm and 33% at a radial position of 30 mm. At a

radial position of 19 mm and a depth of 5 nm, the hardness was 16 GPa and the Young's modulus 212 GPa. At a radial position of 30 mm and a depth of 10 nm, the hardness was 15 GPa and the Young's modulus 205 GPa.

5   On the other hand, 10 discs also having a lubricant layer formed thereon were individually set in a (CSS) evaluation apparatus and tested in the same manner as in Embodiment 1. As a result, all of the 10 discs finished the test without crash, and no injury was detected in the
10 discs by subsequent surface observation. However, when the 10 discs were subjected to a seek test in the same manner as in Embodiment 1, their protective films gradually received slight scratches and were fractured in about 60 seconds, resulting in crash. Thus, it turned out that
15 sample No. 7 produced by the process according to Comparative Example 6 has a sufficient reliability on resistance to sliding in the CSS area but cannot have a sufficient reliability on resistance to sliding in the data area.

Comparative Example 7

20   When a protective filmy layer 5 was formed in the protective-filmy-layer forming chamber 22, Ar gas containing 50% N_2 was introduced into the chamber 22 at a rate of 15 sccm through a mass flow controller. In this case, the pressure was about 0.8 Pa (6.0 mTorr) as measured with a
25 Baratron gauge. Then, DC 1000 W was applied to graphite sintering targets fixed on cathodes located on both sides of the substrate, to induce plasma. In this case, the

discharge current was about 1.25 A and the discharge
voltage about 800 V. By this so-called reactive sputtering
method, the protective filmy layer 5 composed mainly of
carbon and containing a large amount of nitrogen was formed
5   in a thickness of 5 nm within a disc radius of 20.7 mm on a
protective filmy layer 4. In this case, the build-up rate
of the film was 1.1 nm/s.

Sample No. 8 was produced by substantially the
same process as in Embodiment 1 except for the above method
10   for forming the protective filmy layer 5. Sample No. 8 was
evaluated by the same methods as in Embodiment 1. As a
result of ESCA analysis, the following was found: at a
radial position of 19 mm and in a depth range of 0 nm to
about 3 nm from the surface, the proportion of carbon atoms
15   was 73 at.%, the proportion of nitrogen atoms was 25 at.%
and the balance was of other atoms including mainly oxygen.
The following was also found: at a radial position of 30 mm
and in a depth range of 0 nm to about 3 nm from the
surface, the proportion of carbon atoms was 75 at.%, the
20   proportion of nitrogen atoms was 17 at.% and the balance
was of other atoms including mainly oxygen.

As a result of HFS and RBS analyses, it was found
that the percentage of the number of hydrogen atoms based
on the total number of carbon atoms and hydrogen atoms was
25   7% at a radial position of 19 mm and 25% at a radial
position of 30 mm. At a radial position of 19 mm and a
depth of 5 nm, the hardness was 12 GPa and the Young's
modulus 150 GPa. At a radial position of 30 mm and a depth

of 10 nm, the hardness was 20 Gpa and the Young's modulus 248 GPa.

On the other hand, 10 discs also having a lubricant layer formed thereon were individually set in a (CSS) evaluation apparatus and tested in the same manner as in Embodiment 1. As a result, two of the 10 discs finished the test consisting of 50,000 runs of CSS, and no injury was detected in the two discs by subsequent surface observation. However, the 8 other discs underwent crash owing to 10,000 to 25,000 runs of CSS. In addition, when 10 other discs also having a lubricant layer formed thereon were subjected to a seek test and surface observation in the same manner as in Embodiment 1, the surface of the protective film of each disc received some very slight scratches though so-called crash accompanying the fracture of the protective film did not occur. Thus, it turned out that sample No. 8 produced by the process according to Comparative Example 7 has a sufficient reliability on resistance to sliding in the data area but cannot have a sufficient reliability on resistance to sliding in the CSS area.

Comparative Example 8

When a protective filmy layer 4 was formed in the protective-filmy-layer forming chamber 21, Ar gas containing 30% N_2 and 3% H_2 was introduced into the chamber 21 at a rate of 24 sccm through a mass flow controller. In this case, the pressure was about 1 Pa (8.0 mTorr) as measured

with a Baratron gauge. Then, DC 1000 W was applied to
graphite sintering targets fixed on cathodes located on
both sides of the substrate, to induce plasma. In this
case, the discharge current was about 1.6 A and the
5   discharge voltage about 625 V. By this so-called reactive
sputtering method, the protective filmy layer 4 composed
mainly of carbon and containing large amounts of nitrogen
and hydrogen was formed in a thickness of 8 nm on a Co-Cr-
Ta-Pt alloy layer 3. In this case, the build-up rate of
10   the film was 0.95 nm/s.

Sample No. 9 was produced by substantially the
same process as in Embodiment 1 except for the above method
for forming the protective filmy layer 4. Sample No. 9 was
evaluated by the same methods as in Embodiment 1. As a
15   result of ESCA analysis, the following was found: at a
radial position of 19 mm and in a depth range of 0 nm to
about 3 nm from the surface, the proportion of carbon atoms
was 72 at.%, the proportion of nitrogen atoms was 15 at.%
and the balance was of other atoms including mainly oxygen.
20   The following was also found: at a radial position of 30 mm
and in a depth range of 0 nm to about 3 nm from the
surface, the proportion of carbon atoms was 74 at.%, the
proportion of nitrogen atoms was 16 at.% and the balance
was of other atoms including mainly oxygen.

25   As a result of HFS and RBS analyses, it was found
that the percentage of the number of hydrogen atoms based
on the total number of carbon atoms and hydrogen atoms was
5% at a radial position of 19 mm and 15% at a radial

position of 30 mm. At a radial position of 19 mm and a
depth of 5 nm, the hardness was 15 GPa and the Young's
modulus 210 GPa. At a radial position of 30 mm and a depth
of 5 nm, the hardness was 17 GPa and the Young's modulus
5   225 GPa.

On the other hand, 10 discs also having a
lubricant layer formed thereon were individually set in a
(CSS) evaluation apparatus and tested in the same manner as
in Embodiment 1. As a result, all of the 10 discs finished
10   the test without crash, and no injury was detected in the
discs by subsequent surface observation. However, when the
10 discs were subjected to a seek test in the same manner
as in Embodiment 1, their protective films gradually
received slight scratches and were fractured in about 80
15   seconds, resulting in crash. Thus, it turned out that
sample No. 9 produced by the process according to Compara-
tive Example 8 has a sufficient reliability on resistance
to sliding in the CSS area but cannot have a sufficient
reliability on resistance to sliding in the data area.

20   Comparative Example 9

When a protective filmy layer 5 was formed in the
protective-filmy-layer forming chamber 22, Ar gas contain-
ing 10% N_2 was introduced into the chamber 22 at a rate of
15 sccm through a mass flow controller. In this case, the
25   pressure was about 0.8 Pa (6.0 mTorr) as measured with a
Baratron gauge. Then, DC 1000 W was applied to graphite
sintering targets fixed on cathodes located on both sides

of the substrate, to induce plasma. In this case, the discharge current was about 1.35 A and the discharge voltage about 740 V. By this so-called reactive sputtering method, the protective filmy layer 5 composed mainly of

5 carbon and containing a large amount of nitrogen was formed in a thickness of 5 nm within a disc radius of 20.7 mm on a protective filmy layer 4. In this case, the build-up rate of the film was 1.0 nm/s.

Sample No. 10 was produced by substantially the

10 same process as in Embodiment 1 except for the above method for forming the protective filmy layer 5. Sample No. 10 was evaluated by the same methods as in Embodiment 1. As a result of ESCA analysis, the following was found: at a radial position of 19 mm and in a depth range of 0 nm to

15 about 3 nm from the surface, the proportion of carbon atoms was 73 at.%, the proportion of nitrogen atoms was 11 at.% and the balance was of other atoms including mainly oxygen. The following was also found: at a radial position of 30 mm and in a depth range of 0 nm to about 3 nm from the

20 surface, the proportion of carbon atoms was 75 at.%, the proportion of nitrogen atoms was 17 at.% and the balance was of other atoms including mainly oxygen.

As a result of HFS and RBS analyses, it was found that the percentage of the number of hydrogen atoms based

25 on the total number of carbon atoms and hydrogen atoms was 7% at a radial position of 19 mm and 24% at a radial position of 30 mm. At a radial position of 19 mm and a depth of 5 nm, the hardness was 13 GPa and the Young's

modulus 170 GPa. At a radial position of 30 mm and a depth
of 5 nm, the hardness was 19 GPa and the Young's modulus
248 GPa.

On the other hand, 10 discs also having a
5   lubricant layer formed thereon were individually set in a
(CSS) evaluation apparatus and tested in the same manner as
in Embodiment 1. As a result, one of the 10 discs finished
the test consisting of 50,000 runs of CSS, and no injury
was detected in this disc by subsequent surface observa-
10 tion. However, the 9 other discs underwent crash owing to
15,000 to 25,000 runs of CSS. In addition, when 10 other
discs also having a lubricant layer formed thereon were
subjected to a seek test and surface observation in the
same manner as in Embodiment 1, the surface of the
15 protective film of each disc received some very slight
scratches though so-called crash accompanying the fracture
of the protective film did not occur. Thus, it turned out
that sample No. 10 produced by the process according to
Comparative Example 9 has a sufficient reliability on
20 resistance to sliding in the data area but cannot have a
sufficient reliability on resistance to sliding in the CSS
area.

From the results obtained in Embodiment 1 and
Comparative Examples 1 to 9, it was proved that in impart-
25 ing a sufficient reliability on resistance to sliding to a
magnetic disc having a very thin protective film composed
of a protective film of 8 nm thick composed mainly of
carbon in the data area and a protective film of 13 nm

thick composed mainly of carbon in the CSS area, it is
effective that said protective film in the data area is
composed of carbon, nitrogen and hydrogen and has a
hardness of 19 GPa or more as measured by the above-
mentioned measuring method, and that said protective film
in the CSS area is composed of carbon and nitrogen and has
a hardness of 15 to 19 GPa as measured by the above-
mentioned measuring method.

Embodiment 2

A substrate 1 was obtained by plating with Ni-P
the same disc as described in Embodiment 1 except for
changing the dimensions of the disc as follows: outside
diameter 65 mm, inside diameter 20 mm, and thickness 0.8
mm. The substrate 1 was textured so that Ra = 2 nm and Rp
= 15 nm. Then, projections having a height of 15 nm and a
diameter of 3.5 μm were formed thereon at intervals of 10
μm by laser irradiation in the area corresponding to a disc
radius range of 12.13 mm to 15.90 mm, and the thus treated
substrate 1 was thoroughly washed. A magnetic recording
medium comprising the substrate and a primer layer and a
magnetic layer which had been formed on the substrate was
produced in the same manner as in the case of the disc
described in Embodiment 1 except for the above procedure.

Subsequently, this magnetic recording medium was
conveyed to a protective-filmy-layer forming chamber 21,
and a protective filmy layer 4 composed mainly of carbon
and containing large amounts of nitrogen and hydrogen was

formed in a thickness of 8 nm on a Co-Cr-Ta-Pt alloy layer
3 by a so-called reactive sputtering method using Ar gas
containing 30% N_2 and 7.5% H_2.

  Next, the substrate thus treated was conveyed to
5 a protective-filmy-layer forming chamber 22. The
protective-filmy-layer forming chamber 22 is equipped with
the shields against sputtering particles 23 and 24 shown in
Fig. 3, so as to have such a structure that a film is
actively built up only in the whole area within a disc
10 radius of 15.9 mm on the substrate where a magnetic head
comes into contact with a protective film to be formed, at
the time of starting and/or standing of the magnetic head
and that build-up of a film is very difficult outside a
disc radius of 15.9 mm. Ar gas containing 30% N_2 was
15 introduced into the chamber 22 at a rate of 15 sccm through
a mass flow controller while evacuating the chamber 22 with
a turbo molecular pump. In this case, the pressure was
about 0.9 Pa (6.5 mTorr) as measured with a Baratron gauge.

  Then, DC 1000 W was applied to graphite sintering
20 targets fixed on cathodes located on both sides of the
substrate, to induce plasma. In this case, the discharge
current was about 1.4 A and the discharge voltage about 710
V. By this so-called reactive sputtering method, a
protective filmy layer 5 composed mainly of carbon and
25 containing a large amount of nitrogen was formed in a
thickness of 5 nm within a disc radius of 15.9 mm on the
protective filmy layer 4. In this case, the build-up rate
of the film was 1.0 nm/s.

The thus treated substrate was taken out of the
vacuum tank and allowed to cool to room temperature
spontaneously. A plurality of discs were produced in the
manner described above. Some of them were used for
5 analyzing their protective filmy layers. Some others were
subjected to tape cleaning and then provided with a layer
of about 2 nm thick of a fluorocarbon type lubricant, and
after lifting check, they were subjected to a sliding test
singly or subjected to a reliability test after being
10 incorporated into a magnetic disc apparatus.

The protective film of the disc produced in the
manner described above was analyzed at an angle of
detection of 30° by X-ray photoelectron spectroscopy (ESCA).
As a result, the following was found: at a radial position
15 of 15 mm and in a depth range of 0 nm to about 3 nm from
the surface, the proportion of carbon atoms was 75 at.%,
the proportion of nitrogen atoms was 15 at.% and the
balance was of other atoms including mainly oxygen. The
following was also found: at a radial position of 25 mm and
20 in a depth range of 0 nm to about 3 nm from the surface,
the proportion of carbon atoms was 77 at.%, the proportion
of nitrogen atoms was 17 at.% and the balance was of other
atoms including mainly oxygen. Thus, the amount of
nitrogen in the protective filmy layer 4 and that in the
25 protective filmy layer 5 were not widely different.

The protective film was subjected to hydrogen
forward scattering spectroscopy (HFS) under the following
conditions: He + +ion beam energy = 160 fJ (1 MeV); angle

of detection 30°. It was also subjected to Rutherford
backscattering spectroscopy (RBS) at an angle of detection
of 160°. As a result, it was found that the percentage of
the number of hydrogen atoms based on the total number of
5 carbon atoms and hydrogen atoms was 5% at a radial position
of 15 mm and 23% at a radial position of 25 mm, namely, the
protective filmy layer 4 contained a large number of
hydrogen atoms, while the protective filmy layer 5 did not
contain a large number of hydrogen atoms.

10   Then, the hardness and Young's modulus of the
protective film were measured at radial positions of 15 mm
and 25 mm with a thin-film microhardness measuring
apparatus (a nanoindenter) manufactured by Nano Instrument
Co., in a definite-indentation-depth mode by using a
15 Barkovich type diamond indenter having a radius of
curvature of 0.1 μm. As a result, the following was found:
at a radial position of 15 mm and a depth of 5 nm, the
hardness was 17 GPa and the Young's modulus 216 GPa; and at
a radial position of 25 mm and a depth of 5 nm, the hard-
20 ness was 21 GPa and the Young's modulus 241 GPa. Thus, the
protective filmy layer 4 had both a larger hardness value
and a larger Young's modulus value than did the protective
filmy layer 5.

        On the other hand, ten of the discs also having
25 the lubricant layer formed thereon were individually set in
a contact-start-and-stop (CSS) evaluation apparatus and
tested. When the 10 discs were subjected to CSS 50,000
times at a revolution rate of 10,000 r.p.m., all of the 10

discs finished the test without crash, and no injury was
detected in the discs by subsequent microscopic observation
of the surfaces of the discs. Thus, it was proved that the
magnetic recording medium of the present invention has a
5   sufficient reliability on resistance to sliding when the
thickness of the protective film in the area where a
magnetic head performs CSS is 13 nm.

Next, 0.1 g of alumina particles having an
average particle size of 0.1 μm were casted on each of the
10 10 discs while carrying out random seeking of a magnetic
head at 10,000 r.p.m. in the area other than the area where
CSS was carried out, i.e., the so-called data area (corre-
sponding to a disc radius range of 16 mm to 31 mm) where
the protective film did not steadily come into contact with
15 the magnetic head. After 120 seconds of the seeking, the
disc surface was observed. As a result, it was found that
although the surface of the protective film had received
some very slight scratches, so-called crash accompanying
the fracture of the protective film had not occurred.
20 Thus, it was proved that the magnetic recording medium of
the present invention can have a sufficient reliability on
resistance to sliding though the thickness of the protec-
tive film in the data area is as very small as 8 nm. The
above evaluation results are described in Table 1 as those
25 for sample No. 11.

Embodiment 3

A substrate 1 obtained by plating an aluminum

alloy base material (outside diameter 95 mm, inside

diameter 25 mm, thickness 0.8 mm) with Ni-P was textured so

that Ra = 2 nm and Rp = 15 nm. Then, projections having a

height of 15 nm and a diameter of 3.5 μm were formed

5   thereon at intervals of 10 μm by laser irradiation in the

area corresponding to a disc radius R range of 18 to 20.7

mm, and the thus treated substrate 1 was thoroughly washed.

The substrate 1 was introduced into a vacuum tank evacuated

to about 5.3 × 10 E – 5 Pa (4.0 × 10 E – 7 Torr). First,

10   the substrate 1 was conveyed to a heating chamber in the

vacuum tank and heated to 260℃ with an IR heater.

Subsequently, the substrate 1 was conveyed to a

primer-layer forming chamber and a Cr-10 at.% Mo-7.5 at.%

Ti alloy primer layer 2 was formed thereon in a thickness

15   of 30 nm by a DC magnetron sputtering method under an Ar

atmosphere at about 0.8 Pa (6 mTorr). Then, the substrate

1 was conveyed to a magnetic-recording-layer forming

chamber and a Co-20 at.% Cr-4 at.% Ta-8 at.% Pt alloy layer

3 was formed thereon in a thickness of 22 nm by a DC

20   magnetron sputtering method under an Ar atmosphere at about

0.9 Pa (7 mTorr). Using this substrate having the Cr-10

at.% Mo-7.5 at.% Ti alloy primer layer 2 and Co-20 at.%

Cr-4 at.% Ta-8 at.% Pt alloy layer 3 formed thereon, the

following protective filmy layers composed mainly of carbon

25   according to the present invention were formed.

As the above-mentioned substrate 1, there can be

used, for example, rigid substrates made of ceramics of

chemically strengthened aluminosilicate, soda-lime glass,

silicon, borosilicate glass, etc. or made of glass-glazed
ceramics, as well as Al-Mg alloy substrates subjected to
nonelectrode plating with Ni-P.

5   The primer layer 2 is used as a primer film for
controlling the crystalline orientation of the magnetic
layer formed thereon. As the primer layer, there can also
be used thin films of Cr-based alloys such as nonmagnetic
Cr-V, Cr-Ti, Cr-Mo, Cr-Si and Cr-Mo-Ti alloys which form
disordered solid solutions capable of being subjected to
10   (100) orientation good in crystal matching with the
magnetic film. When the primer layer was formed by adding
0.5 vol% to 50 vol% of nitrogen to a gas for discharge used
in the sputtering, the refinement of grains of the primer
layer took place. Consequently, grains of the magnetic
15   layer subsequently formed were also refined, so that medium
noise could be reduced.

As the magnetic layer 3, there can be used not
only Co-Cr-Pt-Ta alloys but also multi-component alloy
systems which are composed mainly of Co, contain Pt for
20   increasing the coercive force and contain Cr, Ta, SiO_2, Nb,
etc. for reducing medium noise. Particularly when Ta, Nb,
V or Ti was added, the melting point of a target was
lowered, so that the progress of component separation of
the magnetic film containing Cr was desirably facilitated.
25   Co-based alloy systems containing Pt, Ni or Mn are
practical because their anisotropy energy does not decrease
so much as that of Co-based alloy systems containing any
other additive element.

Specifically, there can be used alloys such as
Co-Cr-Pt-Ta, Co-Cr-Pt-SiO$_2$, Co-Cr-Pt-Mn, Co-Cr-Nb-Pt, Co-Cr-V-Pt, Co-Cr-Ti-Pt, Co-Cr-Nb-Ta-Pt, Co-Pt-Ni-SiO$_2$, etc., as
well as Co-Cr-Pt. As to the composition of the Co alloy

5   layer constituting the ferromagnetic portion, the amount of
Cr incorporated as a solid solution is considered to be 5
to 10 at.% and the amount of Ta incorporated as a solid
solution about 2 at.%. When the Co alloy magnetic layer is
formed by incorporating Cr and Ta in amounts larger than

10 the above amounts, magnetic separation in the magnetic
layer proceeds, resulting in reduced medium noise.

As a practical composition, there can be used,
for example,

Co-20 at.% Cr-4 at.% Ta-8 at.% Pt alloy,

15 Co-22 at.% Cr-20 at.% Pt alloy,

Co-15 at.% Cr-8 at.% Pt-20 mol.% SiO$_2$ alloy,

Co-17 at.% Cr-12 at.% Pt-5 at.% Mn alloy,

Co-17 at.% Cr-5 at.% Nb-10 at.% Pt alloy,

Co-20 at.% Cr-5 at.% V-12 at.% Pt alloy,

20 Co-20 at.% Cr-10 at.% V-15 at.% Pt alloy, and

Co-15 at.% Cr-5 at.% Nb-5 at.% Ta-20 at.% Pt alloy.

The above-mentioned substrate was conveyed to the
protective-filmy-layer forming chamber 21 shown in Fig. 2
without taking out the substrate from the vacuum tank. Ar

25 gas containing 30% N$_2$ and 5.5% H$_2$ was introduced into the
chamber 21 at a rate of 24 sccm (Standard cubic centimeter
per minute) through a mass flow controller while evacuating
the protective-filmy-layer forming chamber 21 with a turbo

molecular pump. In this case, the pressure was about 1 Pa
(8 mTorr) as measured with a Baratron gauge. Then, DC 1000
W was applied to graphite sintering targets fixed on
cathodes located on both sides of the substrate, to induce
5   plasma. In this case, the discharge current was about 1.5
A and the discharge voltage about 670 V. By this so-called
reactive sputtering method, a protective filmy layer 4
composed mainly of carbon and containing large amounts of
nitrogen and hydrogen was formed in a thickness of 8 nm on
10   the Co-Cr-Ta-Pt alloy layer 3. In this case, the build-up
rate of the film was 0.8 nm/s.

         Next, the thus treated substrate was conveyed to
a protective-filmy-layer forming chamber 22. The
protective-filmy-layer forming chamber 22 is equipped with
15   the shields against sputtering particles 23 and 24 shown in
Fig. 3, so as to have such a structure that a film is
actively built up only in the whole area within a disc
radius of 20.7 mm on the substrate where a magnetic head
comes into contact with a protective film to be formed, at
20   the time of starting and/or standing of the magnetic head
and that build-up of a film is very difficult outside a
disc radius of 20.7 mm. Ar gas containing 25% N_2 was
introduced into the chamber 22 at a rate of 15 sccm through
a mass flow controller while evacuating the protective-
25   filmy-layer forming chamber 22 with a turbo molecular pump.
In this case, the pressure was about 0.9 Pa (6.5 mTorr) as
measured with a Baratron gauge.

         Then, DC 1000 W was applied to graphite sintering

targets fixed on cathodes located on both sides of the
substrate, to induce plasma. In this case, the discharge
current was about 1.4 A and the discharge voltage about 700
V. By this so-called reactive sputtering method, a protec-
5   tive filmy layer 5 composed mainly of carbon and containing
a large amount of nitrogen was formed in a thickness of 5
nm within a disc radius of 20.7 mm on the protective filmy
layer 4. In this case, the build-up rate of the film was
0.5 nm/s.

10   The thus treated substrate was taken out of the
vacuum tank and allowed to cool to room temperature
spontaneously. A plurality of discs were produced in the
manner described above. Some of them were used for
analyzing their protective filmy layers. Some others were
15   subjected to tape cleaning and then provided with a layer
of about 2 nm thick of a fluorocarbon type lubricant, and
after lifting check, they were subjected to a sliding test
singly or subjected to a reliability test after being
incorporated into a magnetic disc apparatus.

20   The protective film of the disc produced in the
manner described above was analyzed at an angle of
detection of 30° by X-ray photoelectron spectroscopy (ESCA).
As a result, the following was found: at a radial position
of 19 mm and in a depth range of 0 nm to about 3 nm from
25   the surface, the proportion of carbon atoms was 78 at.%,
the proportion of nitrogen atoms was 13 at.% and the
balance was of other atoms including mainly oxygen. The
following was also found: at a radial position of 30 mm and

in a depth range of 0 nm to about 3 nm from the surface, the proportion of carbon atoms was 77 at.%, the proportion of nitrogen atoms was 16 at.% and the balance was of other atoms including mainly oxygen. Thus, the amount of

5 nitrogen in the protective filmy layer 4 and that in the protective filmy layer 5 were not widely different.

The protective film was subjected to hydrogen forward scattering spectroscopy (HFS) under the following conditions: He + +ion beam energy = 160 fJ (1 MeV); angle

10 of detection 30°. It was also subjected to Rutherford backscattering spectroscopy (RBS) at an angle of detection of 160°. As a result, it was found that the percentage of the number of hydrogen atoms based on the total number of carbon atoms and hydrogen atoms was 6% at a radial position

15 of 19 mm and 20% at a radial position of 30 mm, namely, the protective filmy layer 4 contained a large number of hydrogen atoms, while the protective filmy layer 5 did not contain a large number of hydrogen atoms.

Then, the hardness and Young's modulus of the

20 protective film were estimated at radial positions of 19 mm and 30 mm. The hardness and Young's modulus referred to here are those measured with a thin-film microhardness measuring apparatus (a nanoindenter) manufactured by Nano Instrument Co., in a definite-indentation-depth mode by

25 using a Barkovich type diamond indenter having a radius of curvature of 0.1 μm. As a result, the following was found: at a radial position of 19 mm and a depth of 5 nm, the hardness was 15 GPa and the Young's modulus 209 GPa; and at

a radial position of 30 mm and a depth of 5 nm, the hardness was 19 GPa and the Young's modulus 236 GPa. Thus, the protective filmy layer 4 had both a larger hardness value and a larger Young's modulus value than did the protective 5 filmy layer 5.

On the other hand, ten of the discs also having the lubricant layer formed thereon were individually set in a contact-start-and-stop (CSS) evaluation apparatus and tested. When the 10 discs were subjected to CSS 50,000 10 times at a revolution rate of 7,500 r.p.m., all of the 10 discs finished the test without crash. When their surfaces after the test were carefully observed under a microscope and carefully and visually observed by oblique light, no injury was detected in the discs. Thus, it was proved that 15 the magnetic recording medium of the present invention has a sufficient reliability on resistance to sliding when the thickness of the protective film in the CSS area is 13 nm.

Next, 0.1 g of alumina particles having an average particle size of 0.1 μm were casted on each of the 20 10 discs while carrying out random seeking of a magnetic head at 7,500 r.p.m. in the area other than the area where CSS was carried out, i.e., the so-called data area (corresponding to a disc radius range of 21 mm to 46 mm) where the protective film did not steadily come into contact with 25 the magnetic head. After 120 seconds of the seeking, the disc surface was observed under a microscope and visually observed by oblique light.

As a result, it was found that although the

surface of the protective film had received some very slight scratches, so-called crash accompanying the fracture of the protective film had not occurred. Thus, it was proved that the magnetic recording medium of the present

5 invention can have a sufficient reliability on resistance to sliding though the thickness of the protective film in the data area is as very small as 8 nm. The above evaluation results are described in Table 1 as those for sample No. 12.

10 Embodiment 4

A substrate 1 obtained by plating an aluminum alloy base material (outside diameter 95 mm, inside diameter 25 mm, thickness 0.8 mm) with Ni-P was textured so that Ra = 2 nm and Rp = 15 nm. Then, projections having a

15 height of 15 nm and a diameter of 3.5 μm were formed thereon at intervals of 10 μm by laser irradiation in the area corresponding to a disc radius R range of 18 to 20.7 mm, and the thus treated substrate 1 was thoroughly washed. The substrate 1 was introduced into a vacuum tank evacuated

20 to about 5.3 × 10 E - 5 Pa (4.0 × 10 E - 7 Torr). First, the substrate 1 was conveyed to a heating chamber in the vacuum tank and heated to 260°C with an IR heater. Then, the substrate 1 was conveyed to a primer-layer forming chamber and a Cr-10 at.% Mo-7.5 at.% Ti alloy primer layer

25 2 was formed thereon in a thickness of 30 nm by a DC magnetron sputtering method under an Ar atmosphere at about 0.8 Pa (6 mTorr).

Subsequently, the substrate 1 was conveyed to a magnetic-recording-layer forming chamber and a Co-20 at.% Cr-4 at.% Ta-8 at.% Pt alloy layer 3 was formed thereon in a thickness of 22 nm by a DC magnetron sputtering method

5   under an Ar atmosphere at about 0.9 Pa (7 mTorr). Using this substrate having the Cr-10 at.% Mo-7.5 at.% Ti alloy primer layer 2 and Co-20 at.% Cr-4 at.% Ta-8 at.% Pt alloy layer 3 formed thereon, the following protective filmy layers composed mainly of carbon according to the present

10 invention were formed.

As the above-mentioned substrate 1, there can be used, for example, rigid substrates made of ceramics of chemically strengthened aluminosilicate, soda-lime glass, silicon, borosilicate glass, etc. or made of glass-glazed

15 ceramics, as well as Al-Mg alloy substrates subjected to nonelectrode plating with Ni-P.

The primer layer 2 is used as a primer film for controlling the crystalline orientation of the magnetic layer formed thereon. As the primer layer, there can also

20 be used thin films of Cr-based alloys such as nonmagnetic Cr-V, Cr-Ti, Cr-Mo, Cr-Si and Cr-Mo-Ti alloys which form disordered solid solutions capable of being subjected to (100) orientation good in crystal matching with the magnetic film. When the primer layer was formed by adding

25 0.5 vol% to 50 vol% of nitrogen to a gas for discharge used in the sputtering, the refinement of grains of the primer layer took place. Consequently, grains of the magnetic layer subsequently formed were also refined, so that medium

noise could be reduced.

As the magnetic layer 3, there can be used not only Co-Cr-Pt-Ta alloys but also multi-component alloy systems which are composed mainly of Co, contain Pt for

5 increasing the coercive force and contain Cr, Ta, SiO_2, Nb, etc. for reducing medium noise. Particularly when Ta, Nb, V or Ti was added, the melting point of a target was lowered, so that the progress of component separation of the magnetic film containing Cr was desirably facilitated.

10 Co-based alloy systems containing Pt, Ni or Mn are practical because their anisotropy energy does not decrease so much as that of Co-based alloy systems containing any other additive element.

Specifically, there can be used alloys such as

15 Co-Cr-Pt-Ta, Co-Cr-Pt-SiO_2, Co-Cr-Pt-Mn, Co-Cr-Nb-Pt, Co-Cr-V-Pt, Co-Cr-Ti-Pt, Co-Cr-Nb-Ta-Pt, Co-Pt-Ni-SiO_2, etc., as well as Co-Cr-Pt. As to the composition of the Co alloy layer constituting the ferromagnetic portion, the amount of Cr incorporated as a solid solution is considered to be 5

20 to 10 at.% and the amount of Ta incorporated as a solid solution about 2 at.%. When the Co alloy magnetic layer is formed by incorporating Cr and Ta in amounts larger than the above amounts, magnetic separation in the magnetic layer proceeds, resulting in reduced medium noise.

25 As a practical composition, there can be used, for example,

Co-20 at.% Cr-4 at.% Ta-8 at.% Pt alloy,

Co-22 at.% Cr-20 at.% Pt alloy,

Co-15 at.% Cr-8 at.% Pt-20 mol.% SiO$_2$ alloy,

Co-17 at.% Cr-12 at.% Pt-5 at.% Mn alloy,

Co-17 at.% Cr-5 at.% Nb-10 at.% Pt alloy,

Co-20 at.% Cr-5 at.% V-12 at.% Pt alloy,

5 Co-20 at.% Cr-10 at.% V-15 at.% Pt alloy, and

Co-15 at.% Cr-5 at.% Nb-5 at.% Ta-20 at.% Pt alloy.

The above-mentioned substrate was conveyed to the protective-filmy-layer forming chamber 21 shown in Fig. 2 without taking out the substrate from the vacuum tank. Ar

10 gas containing 25% N$_2$ and 9% H$_2$ was introduced into the chamber 21 at a rate of 24 sccm (Standard cubic centimeter per minute) through a mass flow controller while evacuating the protective-filmy-layer forming chamber 21 with a turbo molecular pump. In this case, the pressure was about 1 Pa

15 (8 mTorr) as measured with a Baratron gauge. Then, DC 1000 W was applied to graphite sintering targets fixed on cathodes located on both sides of the substrate, to induce plasma. In this case, the discharge current was about 1.6 A and the discharge voltage about 630 V. By this so-called

20 reactive sputtering method, a protective filmy layer 4 composed mainly of carbon and containing large amounts of nitrogen and hydrogen was formed in a thickness of 8 nm on the Co-Cr-Ta-Pt alloy layer 3. In this case, the build-up rate of the film was 0.8 nm/s.

25 Next, the thus treated substrate was conveyed to a protective-filmy-layer forming chamber 22. The protective-filmy-layer forming chamber 22 is equipped with the shields against sputtering particles 23 and 24 shown in

Fig. 3, so as to have such a structure that a film is
actively built up on only in the whole area within a disc
radius of 20.7 mm on the substrate where a magnetic head
comes into contact with a protective film to be formed, at
5 the time of starting and/or standing of the magnetic head
and that build-up of a film is very difficult outside a
disc radius of 20.7 mm. Ar gas containing 35% N_2 was
introduced into the chamber 22 at a rate of 15 sccm through
a mass flow controller while evacuating the protective-
10 filmy-layer forming chamber 22 with a turbo molecular pump.
In this case, the pressure was about 0.9 Pa (6.5 mTorr) as
measured with a Baratron gauge.

Then, DC 1000 W was applied to graphite sintering
targets fixed on cathodes located on both sides of the
15 substrate, to induce plasma. In this case, the discharge
current was about 1.4 A and the discharge voltage about 710
V. By this so-called reactive sputtering method, a protec-
tive filmy layer 5 composed mainly of carbon and containing
a large amount of nitrogen was formed in a thickness of 5
20 nm within a disc radius of 20.7 mm on the protective filmy
layer 4. In this case, the build-up rate of the film was
0.5 nm/s.

The thus treated substrate was taken out of the
vacuum tank and allowed to cool to room temperature
25 spontaneously.

A plurality of discs were produced in the manner
described above. Some of them were used for analyzing
their protective filmy layers. Some others were subjected

to tape cleaning and then provided with a layer of about 2
nm thick of a fluorocarbon type lubricant, and after
lifting check, they were subjected to a sliding test singly
or subjected to a reliability test after being incorporated
5 into a magnetic disc apparatus.

The protective film of the disc produced in the
manner described above was analyzed at an angle of
detection of 30° by X-ray photoelectron spectroscopy (ESCA).
As a result, the following was found: at a radial position
10 of 19 mm and in a depth range of 0 nm to about 3 nm from
the surface, the proportion of carbon atoms was 75 at.%,
the proportion of nitrogen atoms was 19 at.% and the
balance was of other atoms including mainly oxygen. The
following was also found: at a radial position of 30 mm and
15 in a depth range of 0 nm to about 3 nm from the surface,
the proportion of carbon atoms was 77 at.%, the proportion
of nitrogen atoms was 15 at.% and the balance was of other
atoms including mainly oxygen. Thus, the amount of
nitrogen in the protective filmy layer 4 and that in the
20 protective filmy layer 5 were not widely different.

The protective film was subjected to hydrogen
forward scattering spectroscopy (HFS) under the following
conditions: He + +ion beam energy = 160 fJ (1 MeV); angle
of detection 30°. It was also subjected to Rutherford
25 backscattering spectroscopy (RBS) at an angle of detection
of 160°. As a result, it was found that the percentage of
the number of hydrogen atoms based on the total number of
carbon atoms and hydrogen atoms was 7% at a radial position

of 19 mm and 28% at a radial position of 30 mm, namely, the protective filmy layer 4 contained a large number of hydrogen atoms, while the protective filmy layer 5 did not contain a large number of hydrogen atoms.

5   Then, the hardness and Young's modulus of the protective film were estimated at radial positions of 19 mm and 30 mm. The hardness and Young's modulus referred to here are those measured with a thin-film microhardness measuring apparatus (a nanoindenter) manufactured by Nano
10 Instrument Co., in a definite-indentation-depth mode by using a Barkovich type diamond indenter having a radius of curvature of 0.1 μm. As a result, the following was found: at a radial position of 19 mm and a depth of 5 nm, the hardness was 18.5 GPa and the Young's modulus 219 GPa; and
15 at a radial position of 30 mm and a depth of 5 nm, the hardness was 19 GPa and the Young's modulus 240 GPa. Thus, the protective filmy layer 4 had both a larger hardness value and a larger Young's modulus value than did the protective filmy layer 5.

20   On the other hand, ten of the discs also having the lubricant layer formed thereon were individually set in a contact-start-and-stop (CSS) evaluation apparatus and tested. When the 10 discs were subjected to CSS 50,000 times at a revolution rate of 7,500 r.p.m., all of the 10
25 discs finished the test without crash. When their surfaces after the test were carefully observed under a microscope and carefully and visually observed by oblique light, no injury was detected in the discs. Thus, it was proved that

the magnetic recording medium of the present invention has
a sufficient reliability on resistance to sliding when the
thickness of the protective film in the CSS area is 13 nm.

　　　　Next, 0.1 g of alumina particles having an
5　average particle size of 0.1 μm were casted on each of the
10 discs while carrying out random seeking of a magnetic
head at 7,500 r.p.m. in the area other than the area where
CSS was carried out, i.e., the so-called data area (corre-
sponding to a disc radius range of 21 mm to 46 mm) where
10　the protective film did not steadily come into contact with
the magnetic head. After 120 seconds of the seeking, the
disc surface was observed under a microscope and visually
observed by oblique light.

　　　　As a result, it was found that although the
15　surface of the protective film had received some very
slight scratches, so-called crash accompanying the fracture
of the protective film had not occurred. Thus, it was
proved that the magnetic recording medium of the present
invention can have a sufficient reliability on resistance
20　to sliding though the thickness of the protective film in
the data area is as very small as 8 nm. The above evalua-
tion results are described in Table 1 as those for sample
No. 13.

Embodiment 5
25　　　　A substrate 1 was obtained by plating with Ni-P
the same disc as described in Embodiment 1 except for
changing the dimensions of the disc as follows: outside

diameter 84 mm, inside diameter 20 mm, and thickness 0.8

mm. The substrate 1 was textured so that Ra = 2 nm and Rp

= 15 nm. Then, projections having a height of 15 nm and a

diameter of 3.5 μm were formed thereon at intervals of 10

5   μm by laser irradiation in the area corresponding to a disc

radius range of 12.13 mm to 15.90 mm, and the thus treated

substrate 1 was thoroughly washed. A magnetic recording

medium comprising the substrate and a primer layer and a

magnetic layer which had been formed on the substrate was

10 produced in the same manner as in the case of the disc

described in Embodiment 1 except for the above procedure.

Subsequently, this magnetic recording medium was

conveyed to a protective-filmy-layer forming chamber 21,

and a protective filmy layer 4 composed mainly of carbon

15 and containing large amounts of nitrogen and hydrogen was

formed in a thickness of 8 nm on the Co-Cr-Ta-Pt alloy

layer 3 by a so-called reactive sputtering method using Ar

gas containing 30% N_2 and 7.5% H_2.

Next, the substrate thus treated was conveyed to

20 a protective-filmy-layer forming chamber 22. The

protective-filmy-layer forming chamber 22 is equipped with

the shields against sputtering particles 23 and 24 shown in

Fig. 3, so as to have such a structure that a film is

actively built up only in the whole area within a disc

25 radius of 15.9 mm on the substrate where a magnetic head

comes into contact with a protective film to be formed, at

the time of starting and/or standing of the magnetic head

and that build-up of a film is very difficult outside a

disc radius of 15.9 mm. Ar gas containing 30% N_2 was introduced into the chamber 22 at a rate of 15 sccm through a mass flow controller while evacuating the chamber 22 with a turbo molecular pump. In this case, the pressure was

5 about 0.9 Pa (6.5 mTorr) as measured with a Baratron gauge.

Then, DC 1000 W was applied to graphite sintering targets fixed on cathodes located on both sides of the substrate, to induce plasma. In this case, the discharge current was about 1.4 A and the discharge voltage about 710

10 V. By this so-called reactive sputtering method, a protective filmy layer 5 composed mainly of carbon and containing a large amount of nitrogen was formed in a thickness of 5 nm within a disc radius of 15.9 mm on the protective filmy layer 4. In this case, the build-up rate of the film was

15 1.0 nm/s.

The thus treated substrate was taken out of the vacuum tank and allowed to cool to room temperature spontaneously. A plurality of discs were produced in the manner described above. Some of them were used for

20 analyzing their protective filmy layers. Some others were subjected to tape cleaning and then provided with a layer of about 2 nm thick of a fluorocarbon type lubricant, and after lifting check, they were subjected to a sliding test singly or subjected to a reliability test after being

25 incorporated into a magnetic disc apparatus.

The protective film of the disc produced in the manner described above was analyzed at an angle of detection of 30° by X-ray photoelectron spectroscopy (ESCA).

As a result, the following was found: at a radial position
of 15 mm and in a depth range of 0 nm to about 3 nm from
the surface, the proportion of carbon atoms was 74 at.%,
the proportion of nitrogen atoms was 15 at.% and the
5 balance was of other atoms including mainly oxygen. The
following was also found: at a radial position of 25 mm and
in a depth range of 0 nm to about 3 nm from the surface,
the proportion of carbon atoms was 75 at.%, the proportion
of nitrogen atoms was 16 at.% and the balance was of other
10 atoms including mainly oxygen. Thus, the amount of
nitrogen in the protective filmy layer 4 and that in the
protective filmy layer 5 were not widely different.

        The protective film was subjected to hydrogen
forward scattering spectroscopy (HFS) under the following
15 conditions: He + +ion beam energy = 160 fJ (1 MeV); angle
of detection 30°. It was also subjected to Rutherford
backscattering spectroscopy (RBS) at an angle of detection
of 160°. As a result, it was found that the percentage of
the number of hydrogen atoms based on the total number of
20 carbon atoms and hydrogen atoms was 7% at a radial position
of 15 mm and 24% at a radial position of 25 mm, namely, the
protective filmy layer 4 contained a large number of
hydrogen atoms, while the protective filmy layer 5 did not
contain a large number of hydrogen atoms.

25   Then, the hardness and Young's modulus of the
protective film were measured at radial positions of 15 mm
and 25 mm with a thin-film microhardness measuring
apparatus (a nanoindenter) manufactured by Nano Instrument

Co., in a definite-indentation-depth mode by using a
Barkovich type diamond indenter having a radius of
curvature of 0.1 μm. As a result, the following were
found: at a radial position of 15 mm and a depth of 5 nm,
5   the hardness was 16 GPa and the Young's modulus 215 GPa;
and at a radial position of 25 mm and a depth of 5 nm, the
hardness was 20 GPa and the Young's modulus 239 GPa. Thus,
the protective filmy layer 4 had both a larger hardness
value and a larger Young's modulus value than did the
10   protective filmy layer 5.

On the other hand, ten of the discs also having
the lubricant layer formed thereon were individually set in
a contact-start-and-stop (CSS) evaluation apparatus and
tested. When the 10 discs were subjected to CSS 50,000
15   times at a revolution rate of 10,000 r.p.m., all of the 10
discs finished the test without crash, and no injury was
detected in the discs by subsequent microscopic observation
of the surfaces of the discs. Thus, it was proved that the
magnetic recording medium of the present invention has a
20   sufficient reliability on resistance to sliding when the
thickness of the protective film in the area where a
magnetic head performs CSS is 13 nm.

Next, 0.1 g of alumina particles having an
average particle size of 0.1 μm were casted on each of the
25   10 discs while carrying out random seeking of a magnetic
head at 10,000 r.p.m. in the area other than the area where
CSS was carried out, i.e., the so-called data area (corre-
sponding to a disc radius range of 16 mm to 41 mm) where

the protective film did not steadily come into contact with
the magnetic head. After 120 seconds of the seeking, the
disc surface was observed. As a result, it was found that
although the surface of the protective film had received

5   some very slight scratches, so-called crash accompanying
the fracture of the protective film had not occurred.
Thus, it was proved that the magnetic recording medium of
the present invention can have a sufficient reliability on
resistance to sliding though the thickness of the protec-

10 tive film in the data area is as very small as 8 nm. The
above evaluation results are described in Table 1 as those
for sample No. 14.

Table 1

Physical properties of the protective film of each sample and sliding test results

Sample	ESCA-N(at.%)		RBS, HFS-H (%)		Microhardness (GPa)		CSS	Seek
	R 19 mm	R 30 mm	R 19 mm	R 30 mm	R 19 mm	R 30 mm		
1	15	17	8	23	17	21	○	○
2	15	17	22	25	20	20	×	○
3	5	17	7	22	7	21	×	○
4	15	17	5	5	16	17	○	×
5	15	17	25	25	22	20	×	○
6	15	6	5	5	14	6	△	×
7	16	17	5	33	16	15	○	×
8	25	15	7	25	12	20	△	○
9	15	16	5	15	15	17	○	×
10	11	17	7	24	13	19	△	○
11	15(R15mm)	17(R25mm)	5(R15mm)	23(R25mm)	17(R15mm)	21(R25mm)	○	○
12	13	16	6	20	15	19	○	○
13	19	15	7	28	18.5	19	○	○
14	15(R15mm)	16(R25mm)	7(R15mm)	24(R25mm)	16(R15mm)	20(R25mm)	○	○

Embodiments of the present invention are further explained below. Another example of embodiment of the present invention is shown in Fig. 8A, Fig. 8B and Fig. 8C.

Embodiment 6

5   A substrate 1' obtained by plating an aluminum alloy base material (outside diameter 95 mm, inside diameter 25 mm, thickness 0.8 mm) with Ni-P was textured so that Ra = 2 nm and Rp = 15 nm (Ra and Rp are indications of roughness). Then, projections having a height of 15 nm and

10   a diameter of 3.5 μm were formed thereon at intervals of 10 μm by laser irradiation in the area corresponding to a disc radius range of 18.0 to 20.5 mm, and the thus treated substrate 1' was thoroughly washed.

The substrate 1' was introduced into a vacuum

15   tank evacuated to about $5.3 \times 10 E - 5$ Pa ($4.0 \times 10 E - 7$ Torr). First, the substrate 1' was conveyed to a heating chamber in the vacuum tank and heated to 260℃ with an IR heater (infrared heater). Then, the substrate 1' was conveyed to a primer-layer forming chamber and a Cr-10 at.%

20   Mo-7.5 at.% Ti alloy primer layer 2' was formed thereon in a thickness of 30 nm by a DC magnetron sputtering method under an Ar atmosphere at about 0.8 Pa (6 mTorr).

Subsequently, the substrate 1' was conveyed to a magnetic-recording-layer forming chamber and a Co-20 at.%

25   Cr-4 at.% Ta-8 at.% Pt alloy layer 3' (capable of forming a magnetic layer) was formed thereon in a thickness of 22 nm by a DC magnetron sputtering method under an Ar atmosphere

at about 0.9 Pa (7 mTorr). Using this substrate having the
Cr-10 at.% Mo-7.5 at.% Ti alloy primer layer 2' and Co-20
at.% Cr-4 at.% Ta-8 at.% Pt alloy layer 3' formed thereon,
the following protective filmy layers composed mainly of
5 carbon according to the present invention were formed.

As the above-mentioned substrate 1', there can be
used, for example, rigid substrates made of ceramics of
chemically strengthened aluminosilicate, soda-lime glass,
silicon, borosilicate glass, etc. or made of glass-glazed
10 ceramics, as well as Al-Mg alloy substrates subjected to
nonelectrode plating with Ni-P.

The primer layer 2' is used as a primer film for
controlling the crystalline orientation of the magnetic
layer formed thereon. As the primer layer, there can also
15 be used thin films of Cr-based alloys such as nonmagnetic
Cr-V, Cr-Ti, Cr-Mo, Cr-Si and Cr-Mo-Ti alloys which form
disordered solid solutions capable of being subjected to
(100) orientation good in crystal matching with the
magnetic layer. When the primer layer was formed by adding
20 0.5 vol% to 50 vol% of nitrogen to a gas for discharge used
in the sputtering, the refinement of grains of the primer
layer took place. Consequently, grains of the magnetic
layer subsequently formed were also refined, so that medium
noise could be reduced.

25 As the magnetic layer 3', there can be used not
only Co-Cr-Ta-Pt alloys but also multi-component alloy
systems which are composed mainly of Co, contain Pt for
increasing the coercive force and contain Cr, Ta, SiO_2, Nb,

etc. for reducing medium noise. Particularly when Ta, Nb,
V or Ti was added, the melting point of a target was
lowered, so that the progress of component separation of
the magnetic layer containing Cr was desirably facilitated.

5   Co-based alloy systems containing Pt, Ni or Mn
are practical because their anisotropy energy does not
decrease so much as that of Co-based alloy systems contain-
ing any other additive element. Specifically, there can be
used alloys such as Co-Cr-Pt-Ta, Co-Cr-Pt-SiO$_2$, Co-Cr-Pt-Mn,
10 Co-Cr-Nb-Pt, Co-Cr-V-Pt, Co-Cr-Ti-Pt, Co-Cr-Nb-Ta-Pt,
Co-Pt-Ni-SiO$_2$, etc., as well as Co-Cr-Pt. As to the
composition of the Co alloy layer constituting the ferro-
magnetic portion, the amount of Cr incorporated as a solid
solution is considered to be 5 to 10 at.% and the amount of
15 Ta incorporated as a solid solution about 2 at.%. When the
Co alloy magnetic layer is formed by incorporating Cr and
Ta in amounts larger than the above amounts, magnetic
separation in the magnetic layer proceeds, resulting in
reduced medium noise.

20   As a practical composition, there can be used,
for example,
Co-20 at.% Cr-4 at.% Ta-8 at.% Pt alloy,
Co-22 at.% Cr-20 at.% Pt alloy,
Co-15 at.% Cr-8 at.% Pt-20 mol.% SiO$_2$ alloy,
25 Co-17 at.% Cr-12 at.% Pt-5 at.% Mn alloy,
Co-17 at.% Cr-5 at.% Nb-10 at.% Pt alloy,
Co-20 at.% Cr-5 at.% V-12 at.% Pt alloy,
Co-20 at.% Cr-10 at.% V-15 at.% Pt alloy, and

Co-15 at.% Cr-5 at.% Nb-5 at.% Ta-20 at.% Pt alloy.

In Fig. 8A, the left side of the diagram shows
the inner-periphery side on which the projections are
present, i.e., the CSS area. The right side of the diagram

5   shows the outer-periphery side, i.e., the data area.

The above-mentioned substrate was conveyed to the
protective-filmy-layer forming chamber 21' shown in Fig. 9,
i.e., a chamber for forming a protective filmy layer by an
ion beam method, without taking out the substrate from the

10   vacuum tank. The protective-filmy-layer forming chamber
21' comprises ion guns consisting of a hot filament 22', an
anode 23' and a grid 24' located in front of the hot
filament. The protective-filmy-layer forming chamber 21'
is also equipped with shields against deposited particles

15   25' so as to have such a structure that a film is actively
built up only in the whole area within a disc radius of
20.7 mm on the substrate where a magnetic head comes into
contact with a protective film to be formed, at the time of
starting and/or standing of the magnetic head and that

20   build-up of a film is very difficult outside a disc radius
of 20.7 mm. That is, a film is formed only on the inner-
periphery side of the disc, i.e., the CSS area, by the ion
beam method. From behind the anode, Ar gas and ethylene
(C_2H_4) gas were introduced into the chamber 21', each at a

25   rate of 15 sccm (Standard Cubic centimeter per minute)
through a mass flow controller while evacuating the
protective-filmy-layer forming chamber 21' with a turbo
molecular pump. In this case, the pressure was about 0.5

Pa (4 mTorr) as measured with a Baratron gauge.

Then, plasma was induced by applying 350 mA and direct current +120 V to the hot filament and anode, respectively, of each of the ion guns located on both sides

5   of the substrate. Ions were extracted by applying -530 V to the grids. Further, a pulse bias of -80 V and 3 kHz was applied to the substrate. In this case, the anode current was 500 mA and the bias current of the substrate was 120 mA. By this so-called ion beam deposition method (IBD), a

10 DLC protective filmy layer 4' composed mainly of carbon and hydrogen was formed in a thickness of 5 nm within a disc radius of 20.7 mm on the Co-Cr-Ta-Pt alloy layer 3'. In this case, the build-up rate of the film was 1.0 nm/s.

Subsequently, the thus treated substrate was

15 conveyed to the protective-filmy-layer forming chamber 31' shown in Fig. 10, i.e., a chamber for forming a protective filmy layer by a sputtering method. Ar gas containing 30% N_2 and 6.0% H_2 was introduced into the chamber 31' at a rate of 24 sccm through a mass flow controller while evacuating

20 the protective-filmy-layer forming chamber 31' with a turbo molecular pump. In this case, the pressure was about 1 Pa (8 mTorr) as measured with a Baratron gauge. Then, DC 1000 W was applied to graphite sintering targets fixed on cathodes located on both sides of the substrate, to induce

25 plasma. In this case, the discharge current was about 1.5 A and the discharge voltage about 670 V. By this so-called reactive sputtering method, an amorphous carbon protective filmy layer 5' composed mainly of carbon and nitrogen and

containing hydrogen was formed in a thickness of 6 nm on
substantially the whole surface of the substrate carrying
the protective filmy layer 4'. In this case, the build-up
rate of the film was 0.8 nm/s.

5   Consequently, as shown in Fig. 8B, the protective
filmy layers were combined as follows: a two-layer struc-
ture having a total thickness of 11 nm was formed of the
DLC layer and the amorphous carbon layer within a disc
radius of 20.7 mm, and the amorphous carbon layer having a
10   thickness of 6 nm was present alone outside a disc radius
of 20.7 mm. The thus treated substrate was taken out of
the vacuum tank and allowed to cool to room temperature
spontaneously.

          A plurality of discs were produced in the manner
15   described above. Some of them were used for analyzing
their protective filmy layers. Some others were subjected
to tape cleaning and then provided with a layer of about 2
nm thick of a fluorocarbon type lubricant, and after
lifting check, they were subjected to a sliding test singly
20   or subjected to a reliability test after being incorporated
into a magnetic disc apparatus.

          The total thickness of the protective filmy
layers of the disc produced in the manner described above
was measured with an ellipsometer at a 0.1-mm pitch from
25   the contact-start-and-stop (CSS) area to the area other
than the CSS area, i.e., the so-called data area where the
protective film did not steadily come into contact with a
magnetic head. As a result, it was found that the

transient area where 90% of the thickness in the CSS area,
i.e., 9.9 nm, decreased to 110% of the thickness in the
data area, i.e., 6.6 nm, had a length of 2.6 mm in the
radial direction.

5   That is, as can be seen with reference to Fig.
8C, it is substantially impossible in practice to form the
DLC layer in the CSS area vertically as schematically shown
in Fig. 8B, in the boundary between the CSS area and the
data area. Therefore, the DLC layer is laminated with a
10 certain degree of gradient. When the difference between a
disc radius R1 at a position corresponding to 90% of the
thickness A in the CSS area and a disc radius R2 at a
position corresponding to 110% of the thickness B in the
data area (R2 - R1) is employed as a numeral value indicat-
15 ing the laminated state at the boundary, the smaller the
difference (namely, the smaller the transient area), the
steeper the boundary surface. It may be safely be said
that when the above-mentioned difference is less than 5,
the boundary surface is steep. For assuring the strength
20 in the CSS area, the ratio A/B is preferably 1.3 or more.

          The reason why the above-mentioned indication of
extent of the transient area between the CSS area and the
data area was less than 5 in Embodiment 6 is that the DLC
layer was formed only in the CSS area by the ion beam
25 method. It was found that in the case of a sputtering
method, ions pass around behind shields, so that the steep-
ness of a formed film in the boundary is lower than in the
case of the ion beam method.

Raman spectroscopic analysis was carried out in order to investigate the structures of the protective filmy layers of the disc produced in the manner described above. For the sake of simplicity, there was used a disc having

5   no protective filmy layer 4' formed thereon and a disc having no protective filmy layer 5' formed thereon. There were employed Raman spectroscopic analysis apparatus 2010 manufactured by Lennie-Shaw Co., an Ar laser (514.5 nm), and a measuring wave number of 1000 to 1800, or 1000 to

10 2300/cm. As a result, it could be confirmed that the protective filmy layer 4' was a typical DLC film, because as shown in Fig. 11, the protective filmy layer 4' had such characteristics that it showed only one peak near 1550 kaysers (1550 (1/cm) on the axis of abscissa in Fig. 11)

15 and did not show a large peak near 1350 kaysers.

As shown in Fig. 12, the protective filmy layer 5' showed a typical waveform of amorphous carbon which had a broad peak from 900 to 1800/cm, and it showed a vibration peak due to a terminal bond $-C{\equiv}N$ for $C=N$ in the vicinity of

20 2230/cm. By the fact that the background showed a gentle slope from 900 to 2300/cm, it could be confirmed that the protective filmy layer 5' was formed of amorphous carbon containing both a large amount of nitrogen and hydrogen.

On the other hand, ten of the discs also having

25 the lubricant layer formed thereon were individually set in a contact-start-and-stop (CSS) evaluation apparatus and tested. When the 10 discs were subjected to CSS 50,000 times at a revolution rate of 7,500 r.p.m., all of the 10

discs finished the test without crash. When their surfaces
after the test were carefully observed under a microscope
and carefully and visually observed by oblique light, no
injury was detected in the discs. Thus, it was proved that
5 the magnetic recording medium of the present invention has
a sufficient reliability on resistance to sliding when the
thickness of the protective film in the area where a
magnetic head performs CSS is 11 nm.

Next, 0.1 g of alumina particles having an
10 average particle size of 0.1 μm were casted on each of the
10 discs while carrying out random seeking of a magnetic
head at 7,500 r.p.m. in the area other than the area where
CSS was carried out, i.e., the so-called data area (corre-
sponding to a disc radius range of 21 mm to 46 mm) where
15 the protective film did not steadily come into contact with
the magnetic head. After 120 seconds of the seeking, the
disc surface was observed under a microscope and visually
observed by oblique light. As a result, it was found that
although the surface of the protective film had received
20 some very slight scratches, so-called crash accompanying
the fracture of the protective film had not occurred.
Thus, it was proved that the magnetic recording medium of
the present invention can have a sufficient reliability on
resistance to sliding though the thickness of the protec-
25 tive filmy layer in the data area is as very small as 6 nm.

Embodiment 7

A substrate 1' obtained by plating an aluminum

alloy base material (outside diameter 95 mm, inside
diameter 25 mm, thickness 0.8 mm) with Ni-P was textured so
that Ra = 2 nm and Rp = 15 nm (Ra and Rp are indications of
roughness). Then, projections having a height of 15 nm and
5   a diameter of 3.5 μm were formed thereon at intervals of 10
μm by laser irradiation in the area corresponding to a disc
radius range of 18.0 to 20.5 mm, and the thus treated
substrate 1' was thoroughly washed.

The substrate 1' was introduced into a vacuum
10   tank evacuated to about 5.3 × 10 E – 5 Pa (4.0 × 10 E – 7
Torr). First, the substrate 1' was conveyed to a heating
chamber in the vacuum tank and heated to 260℃ with an IR
heater (infrared heater). Then, the substrate 1' was
conveyed to a primer-layer forming chamber and a Cr-10 at.%
15   Mo-7.5 at.% Ti alloy primer layer 2' was formed thereon in
a thickness of 30 nm by a DC magnetron sputtering method
under an Ar atmosphere at about 0.8 Pa (6 mTorr).

Subsequently, the substrate 1' was conveyed to a
magnetic-recording-layer forming chamber and a Co-20 at.%
20   Cr-4 at.% Ta-8 at.% Pt alloy layer 3' (capable of forming a
magnetic layer) was formed thereon in a thickness of 22 nm
by a DC magnetron sputtering method under an Ar atmosphere
at about 0.9 Pa (7 mTorr). Using this substrate having the
Cr-10 at.% Mo-7.5 at.% Ti alloy primer layer 2' and Co-20
25   at.% Cr-4 at.% Ta-8 at.% Pt alloy layer 3' formed thereon,
the following protective filmy layers composed mainly of
carbon according to the present invention were formed.

As the above-mentioned substrate 1', there can be

used, for example, rigid substrates made of ceramics of
chemically strengthened aluminosilicate, soda-lime glass,
silicon, borosilicate glass, etc. or made of glass-glazed
ceramics, as well as Al-Mg alloy substrates subjected to
5   nonelectrode plating with Ni-P.

       The primer layer 2' is used as a primer film for
controlling the crystalline orientation of the magnetic
layer formed thereon. As the primer layer, there can also
be used thin films of Cr-based alloys such as nonmagnetic
10   Cr-V, Cr-Ti, Cr-Mo, Cr-Si and Cr-Mo-Ti alloys which form
disordered solid solutions capable of being subjected to
(100) orientation good in crystal matching with the
magnetic layer. When the primer layer was formed by adding
0.5 vol% to 50 vol% of nitrogen to a gas for discharge used
15   in the sputtering, the refinement of grains of the primer
layer took place. Consequently, grains of the magnetic
layer subsequently formed were also refined, so that medium
noise could be reduced.

       As the magnetic layer 3', there can be used not
20   only Co-Cr-Ta-Pt alloys but also multi-component alloy
systems which are composed mainly of Co, contain Pt for
increasing the coercive force and contain Cr, Ta, SiO_2, Nb,
etc. for reducing medium noise. Particularly when Ta, Nb,
V or Ti was added, the melting point of a target was
25   lowered, so that the progress of component separation of
the magnetic layer containing Cr was desirably facilitated.

       Co-based alloy systems containing Pt, Ni or Mn
are practical because their anisotropy energy does not

decrease so much as that of Co-based alloy systems contain-
ing any other additive element. Specifically, there can be
used alloys such as Co-Cr-Pt-Ta, Co-Cr-Pt-SiO$_2$, Co-Cr-Pt-Mn,
Co-Cr-Nb-Pt, Co-Cr-V-Pt, Co-Cr-Ti-Pt, Co-Cr-Nb-Ta-Pt,

5 Co-Pt-Ni-SiO$_2$, etc., as well as Co-Cr-Pt. As to the
composition of the Co alloy layer constituting the ferro-
magnetic portion, the amount of Cr incorporated as a solid
solution is considered to be 5 to 10 at.% and the amount of
Ta incorporated as a solid solution about 2 at.%. When the

10 Co alloy magnetic layer is formed by incorporating Cr and
Ta in amounts larger than the above amounts, magnetic
separation in the magnetic layer proceeds, resulting in
reduced medium noise.

As a practical composition, there can be used,

15 for example,

Co-20 at.% Cr-4 at.% Ta-8 at.% Pt alloy,

Co-22 at.% Cr-20 at.% Pt alloy,

Co-15 at.% Cr-8 at.% Pt-20 mol.% SiO$_2$ alloy,

Co-17 at.% Cr-12 at.% Pt-5 at.% Mn alloy,

20 Co-17 at.% Cr-5 at.% Nb-10 at.% Pt alloy,

Co-20 at.% Cr-5 at.% V-12 at.% Pt alloy,

Co-20 at.% Cr-10 at.% V-15 at.% Pt alloy, and

Co-15 at.% Cr-5 at.% Nb-5 at.% Ta-20 at.% Pt alloy.

The above-mentioned substrate was conveyed to the

25 protective-filmy-layer forming chamber 31' shown in Fig.
10, i.e., a chamber for forming a protective filmy layer by
a sputtering method, without taking out the substrate from
the vacuum tank. Ar gas containing 30% N$_2$ and 6.0% H$_2$ was

introduced into the chamber 31' at a rate of 24 sccm
through a mass flow controller while evacuating the
protective-filmy-layer forming chamber 31' with a turbo
molecular pump. In this case, the pressure was about 1 Pa

5 (8 mTorr) as measured with a Baratron gauge. Then, DC 1000
W was applied to graphite sintering targets fixed on
cathodes located on both sides of the substrate, to induce
plasma. In this case, the discharge current was about 1.5
A and the discharge voltage about 670 V. By this so-called

10 reactive sputtering method, an amorphous carbon protective
filmy layer 5' composed mainly of carbon and nitrogen and
containing hydrogen was formed in a thickness of 6 nm on
the Co-Cr-Ta-Pt alloy layer 3' all over the CSS area and
the data area. In this case, the build-up rate of the film

15 was 0.8 nm/s.

Next, the thus treated substrate was conveyed to
the protective-filmy-layer forming chamber 21' shown in
Fig. 9, i.e., a chamber for forming a protective filmy
layer by an ion beam method. The protective-filmy-layer

20 forming chamber 21' comprises ion guns consisting of a hot
filament 22', an anode 23' and a grid 24' located in front
of the hot filament. The protective-filmy-layer forming
chamber 21' is also equipped with the shields against
deposited particles 25' shown in Fig. 9, so as to have such

25 a structure that a film is actively built up only in the
whole area within a disc radius of 20.7 mm on the substrate
where a magnetic head comes into contact with a protective
film to be formed, at the time of starting and/or standing

of the magnetic head and that build-up of a film is very difficult outside a disc radius of 20.7 mm. From behind the anode, Ar gas and ethylene (C_2H_4) gas were introduced into the chamber 21', each at a rate of 15 sccm, through a

5   mass flow controller while evacuating the protective-filmy-layer forming chamber 21' with a turbo molecular pump. In this case, the pressure was about 0.5 Pa (4 mTorr) as measured with a Baratron gauge.

Then, plasma was induced by applying 350 mA and

10   direct current +120 V to the hot filament and anode, respectively, of each of the ion guns located on both sides of the substrate. Ions were extracted by applying -530 V to the grids. Further, a pulse bias of -80 V and 3 kHz was applied to the substrate. In this case, the anode current

15   was 500 mA and the bias current of the substrate was 120 mA. By this so-called ion beam deposition method (IBD), a DLC protective filmy layer 4' composed mainly of carbon and hydrogen was formed in a thickness of 5 nm within a disc radius of 20.7 mm on the protective filmy layer 5'. Thus,

20   on the inner-periphery side of the disc, i.e., the CSS area, the amorphous carbon protective filmy layer 5' was formed on the magnetic layer and the DLC layer 4' was formed on the protective filmy layer 5'. In this case, the build-up rate of the film was 1.0 nm/s. Consequently, the

25   protective filmy layers were combined as follows: a two-layer structure having a total thickness of 11 nm was formed of the amorphous carbon layer and the DLC layer within a disc radius of 20.7 mm, and the amorphous carbon

layer having a thickness of 6 nm was present alone outside
a disc radius of 20.7 mm. The thus treated substrate was
taken out of the vacuum tank and allowed to cool to room
temperature spontaneously.

5   A plurality of discs were produced in the manner
described above. Some of them were used for analyzing
their protective filmy layers. Some others were subjected
to tape cleaning and then provided with a layer of about 2
nm thick of a fluorocarbon type lubricant, and after
10 lifting check, they were subjected to a sliding test singly
or subjected to a reliability test after being incorporated
into a magnetic disc apparatus.

           The total thickness of the protective filmy
layers of the disc produced in the manner described above
15 was measured with an ellipsometer at a 0.1-mm pitch from
the contact-start-and-stop (CSS) area to the area other
than the CSS area, i.e., the so-called data area where the
protective film did not steadily come into contact with a
magnetic head. As a result, it was found that the
20 transient area where 90% of the thickness in the CSS area,
i.e., 9.9 nm, decreased to 110% of the thickness in the
data area, i.e., 6.6 nm, had a length of 2.4 mm in the
radial direction.

           Raman spectroscopic analysis was carried out in
25 order to investigate the structures of the protective filmy
layers of the disc produced in the manner described above.
For the sake of simplicity, there were used a disc having
no protective filmy layer 4' formed thereon and a disc

having no protective filmy layer 5' formed thereon. There
were employed Raman spectroscopic analysis apparatus 2010
manufactured by Lennie-Shaw Co., an Ar laser (514.5 nm),
and a measuring wave number of 1000 to 1800, or 1000 to

5   2300/cm.

As a result, it could be confirmed that the
protective filmy layer 4' was a typical DLC film, because
as shown in Fig. 11, the protective filmy layer 4' had such
characteristics that it showed only one peak near 1550

10   kaysers (1550 (1/cm) on the axis of abscissa in Fig. 11)
and did not show a large peak near 1350 kaysers.

As shown in Fig. 12, the protective filmy layer
5' showed a typical waveform of amorphous carbon which had
a broad peak from 900 to 1800/cm, and it showed a vibration

15   peak due to a terminal bond $-C \equiv N$ for $C=N$ in the vicinity of
2230/cm. By the fact that the background showed a gentle
slope from 900 to 2300/cm, it could be confirmed that the
protective filmy layer 5' was formed of amorphous carbon
containing both a large amount of nitrogen and hydrogen.

20   On the other hand, ten of the discs also having
the lubricant layer formed thereon were individually set in
a contact-start-and-stop (CSS) evaluation apparatus and
tested. When the 10 discs were subjected to CSS 50,000
times at a revolution rate of 7,500 r.p.m., all of the 10

25   discs finished the test without crash. When their surfaces
after the test were carefully observed under a microscope
and carefully and visually observed by oblique light, no
injury was detected in the discs. Thus, it was proved that

the magnetic recording medium of the present invention has a sufficient reliability on resistance to sliding when the thickness of the protective film in the area where a magnetic head performs CSS is 11 nm.

5   Next, 0.1 g of alumina particles having an average particle size of 0.1 μm were casted on each of the 10 discs while carrying out random seeking of a magnetic head at 7,500 r.p.m. in the area other than the area where CSS was carried out, i.e., the so-called data area (corre-

10   sponding to a disc radius range of 21 mm to 46 mm) where the protective film did not steadily come into contact with the magnetic head. After 120 seconds of the seeking, the disc surface was observed under a microscope and visually observed by oblique light. As a result, it was found that

15   although the surface of the protective film had received some very slight scratches, so-called crash accompanying the fracture of the protective film had not occurred. Thus, it was proved that the magnetic recording medium of the present invention can have a sufficient reliability on

20   resistance to sliding though the thickness of the protective filmy layer in the data area is as very small as 6 nm.

Comparative Example 10

          Discs were produced by substantially the same process as in Embodiment 6 except that no DLC protective

25   filmy layer 4' was formed. That is, substantially the whole surface of each disc had only an amorphous carbon protective filmy layer 5' as a protector. Ten discs also

having a lubricant layer formed thereon were individually set in a (CSS) evaluation apparatus and tested in the same manner as in Embodiment 6. As a results, all of the 10 discs underwent crash owing to less than 1,000 runs of CSS.

5   In addition, when 10 other discs also having a lubricant layer formed thereon were subjected to a seek test and surface observation in the same manner as in Embodiment 6, the surface of the protective film of each disc received some very slight scratches, though so-called crash

10 accompanying the fracture of the protective film did not occur. Thus, it turned out that the disc produced accord-ing to Comparative Example 10 has a sufficient reliability on resistance to sliding in the data area but cannot have a sufficient reliability on resistance to sliding in the area

15 where CSS is carried out.

Comparative Example 11

        No amorphous carbon protective filmy layer 5' was formed and no shield against deposited particles was used for forming a DLC protective filmy layer 4'. Thus,

20 substantially the whole surface of each disc was covered with the DLC protective film. In this case, the protective filmy layer 4' was formed in a thickness of 5 nm. Except for the above, discs were produced by substantially the same process as in Embodiment 6. Ten discs also having a

25 lubricant layer formed thereon were individually set in a (CSS) evaluation apparatus and tested in the same manner as in Embodiment 6.

As a result, all of the 10 discs underwent crash owing to less than 7,000 runs of CSS. In addition, when 10 other discs also having a lubricant layer formed thereon were subjected to a seek test and surface observation in 5 the same manner as in Embodiment 6, the surface of the protective film of each disc received some very slight scratches, though so-called crash accompanying the fracture of the protective film did not occur. Thus, it turned out that the disc produced according to Comparative Example 11 10 has a sufficient reliability on resistance to sliding in the data area but cannot have a sufficient reliability on resistance to sliding in the area where CSS is carried out.

Comparative Example 12

A chamber comprising the same guns for sputtering 15 as those of the protective-filmy-layer forming chamber 31' was used as the protective-filmy-layer forming chamber 21'. The shields were not removed in order that the adhesion of sputtering particles might be difficult outside a disc radius of 20.7 mm. When a protective filmy layer 4' was 20 formed in the protective-filmy-layer forming chamber 21', Ar gas containing 30% N_2 and 6.0% H_2 was introduced into the chamber 21' at a rate of 24 sccm through a mass flow controller. In this case, the pressure was about 1.0 Pa (8.0 mTorr) as measured with a Baratron gauge.

25 Then, DC 1000 W was applied to graphite sintering targets fixed on cathodes located on both sides of the substrate, to induce plasma. In this case, the discharge

current was about 1.5 A and the discharge voltage about 670

V. By this so-called reactive sputtering method, the

protective filmy layer 4' composed mainly of carbon and

nitrogen and containing a large amount of hydrogen was

5   formed in a thickness of 5 nm within a disc radius of 20.7

mm on a Co-Cr-Ta-Pt alloy layer 3'. In this case, the

build-up rate of the film was 0.8 nm/s. Except for the

above process for forming the protective filmy layer 4',

discs were produced by substantially the same process as in

10   Example 6.

The total thickness of the protective filmy

layers of the disc produced in the manner described above

was measured with an ellipsometer at a 0.1-mm pitch from

the contact-start-and-stop (CSS) area to the area other

15   than the CSS area, i.e., the so-called data area where the

protective film did not steadily come into contact with a

magnetic head. As a result, it was found that the

transient area where 90% of the thickness in the CSS area,

i.e., 9.9 nm, decreased to 110% of the thickness in the

20   data area, i.e., 6.6 nm, had a length of 8.7 mm in the

radial direction.

Thus, the following was found: when the reactive

sputtering method is used for forming the protective filmy

layer 4', the film thickness cannot be abruptly increased

25   as that in the CSS area in a short distance even by the use

of the same shields as used in the ion beam deposition

method, so that it is impossible to assure the uniformity

of the film thickness in the data area and assure the film

thickness in the CSS are as desired. Ten discs also having a lubricant layer formed thereon were individually set in a (CSS) evaluation apparatus and tested in the same manner as in Embodiment 6.

5   As a results, all of the 10 discs underwent crash owing to less than 25,000 runs of CSS. In addition, when 10 other discs also having a lubricant layer formed thereon were subjected to a seek test and surface observation in the same manner as in Embodiment 6, the surface of the

10 protective film of each disc received some very slight scratches, though so-called crash accompanying the fracture of the protective film did not occur. Thus, it turned out that the disc produced according to Comparative Example 12 has a sufficient reliability on resistance to sliding in

15 the data area but cannot have a sufficient reliability on resistance to sliding in the area where CSS is carried out.

Embodiment 8

          The same discs as described in each of Embodi-
ments 1 to 7 were subjected to 50,000 runs of the CSS

20 sliding resistance test to find that in the case of all magnetic recording media having a magnetic film of 15 nm, 17 nm or 21 nm in thickness, neither the magnetic recording madia nor a magnetic head were destroyed, namely, a satisfactory reliability on resistance to sliding could be

25 attained.

          When the thickness of the magnetic layer was reduced, the product of the thickness t of the magnetic

layer and the residual magnetic flux density Br, Br × t is
markedly reduced. The in-plane coercive force Hc was
approximately 176 kA/m to 256 kA/m, the coercive force
squareness ratio S* was about 0.7 (in a range of 0.74 to
5   0.65), and the squareness ratio S was 0.78 to 0.7. These
magnetic characteristics were measured at 25℃ with a sample
vibration type magnetometer.

        The electromagnetic transduction characteristics
of the above-mentioned magnetic recording media were
10   measured by using a magnetic head having a shield gap
length Gs of magnetoresistance effect type reproducing
element (MR element) of 0.18 μm and a gap length of writing
element of 0.3 μm. The sense current of the MR element was
adjusted to 6 mA and the writing current Iw to 41 mA. The
15   output half-value width PW 50 of solitary regenerative wave
was measured with a digital oscilloscope (Tektronix
TDS544A) by varying the revolution rate of each magnetic
recording medium (each magnetic disc medium) and the degree
of lifting of the head. The thinner the magnetic film and
20   the lower the degree of lifting of the magnetic head, the
smaller the value of PW 50. A small PW 50 value of 240 nm
was obtained when the thickness of the magnetic film was 15
nm and the degree of lifting of the head was 25 nm.

        The output at a maximum line packing density 360
25   kFCI which had been measured with a spectrum analyzer was 1
to 2% based on the output of solitary regenerative wave at
10 kFCI which had been measured with the digital oscillo-
scope. This output at a maximum line packing density 360

kFCI measured with a spectrum analyzer was a value obtained by adding up the outputs of waveforms in odd numbers until the frequency exceeded 100 MHz. In addition, the ratio of the O-p output of solitary regenerative wave (SLF) to

5   integrated medium noise (Nd) in the case of recording signals at 360 kFCL, SLF/Nd was estimated. In this case, the degree of lifting of the head was adjusted to 25 nm and Nd was a value obtained by integrating noise in a zone corresponding to a range of 0.5 kFCI to 540 kFCI. For all

10   the media, a high SLF/Nd ratio of 24 dB or more was obtained at a high packing density of 360 kFCI.

        As shown in Fig. 4, there was constructed a magnetic storage comprising each of the above-mentioned magnetic disc media 61, a driving unit 62 for driving said

15   magnetic recording medium, a magnetic head composed of a recording portion and reproducing portion, a means 64 for moving said magnetic head in relation to said magnetic recording medium, and means 65, i.e., a means for inputting signals into said magnetic head and a record reproduction

20   signal processing means for reproducing signals outputted from said magnetic head.

        Fig. 5 is a schematic perspective view of the above-mentioned magnetic head used for the measurement whose reproducing portion is composed of a magneto-

25   resistance effect type magnetic head. Said head is a composite head having both an electromagnetic induction type head for recording and the magnetoresistance effect type magnetic head for reproduction which are formed on a

base 601. Said head for recording is composed of an upper
recording magnetic pole 603 and a lower recording magnetic
pole and upper shield layer 604 which hold a coil 602
between them. The gap length between the recording
5 magnetic poles was adjusted to 0.3 μm. A copper wire of 3
μm thick was used as the coil. Said head for reproduction
is composed of a magnetoresistance sensor 605 and electrode
patterns 606 located on both sides of the magnetoresistance
sensor 605. The magnetoresistance sensor is held between
10 the lower recording magnetic pole and upper shield layer
604 and a lower shield layer 607, both of which have a
thickness of 1 μm. The distance between said shield layers
is 0.2 μm. In Fig. 5, a gap layer between the recording
magnetic poles and gap layers between each shield layer and
15 the magnetoresistance sensor are omitted.

Fig. 6 shows the structure of a section of the
magnetoresistance sensor. The signal detection region 701
of the magnetic sensor is composed of a portion obtained by
forming a lateral bias layer 702, a separating layer 703
20 and a magnetoresistance ferromagnetic layer 704 in that
order on a gap layer 700 of aluminum oxide. A Ni-Fe alloy
layer of 20 nm thick was used as the magnetoresistance
ferromagnetic layer 704. Although a Ni-Fe-Nb alloy layer
of 25 nm thick was used as the lateral bias layer 702, any
25 other ferromagnetic alloy having a relatively high electric
resistance and good soft-magnetic characteristics, such as
Ni-Fe-Rh may also be used. The lateral bias layer 702 is
magnetized in a film in-plane direction (a lateral

direction) perpendicular to a sense current flowing through the magnetoresistance ferromagnetic layer 704, by a magnetic field generated by said current, and applies a lateral bias magnetic field to the magnetoresistance ferro-

5   magnetic layer 704. A magnetic sensor capable of thus exhibiting a linear reproduction output for a magnetic field leaking out of the media 61 is chosen. Ta having a relatively high electric resistance was used in the separating layer 703 for preventing the diversion of a

10 sense current from the magnetoresistance ferromagnetic layer 704, and the thickness of the separating layer 703 was adjusted to 5 nm.

A tapered portion 705 formed by tapering is present on each side of the signal detection region. The

15 tapered portion 705 is composed of a permanent-magnet layer 706 for making the magnetoresistance ferromagnetic layer 704 into a single domain, and a pair of electrodes formed thereon for taking out signals. The permanent-magnet layer 706 has to have a large coercive force and its direction of

20 magnetization must not be easily changed. Any of alloys such as Co-Cr, Co-Cr-Pt, etc. is used in the permanent-magnet layer 706.

The magnetic storage shown in Fig. 4 was constructed by combining the magnetic recording medium

25 described in each of Embodiments 1 to 7 with the above-mentioned head shown in Fig. 5. As a result, in the case of a lifting system with a magnetic lifting altitude hm of approximately 48 - 60 nm, when the product of the thickness

t of the magnetic layer and the residual magnetic flux
density Br measured by applying a magnetic field in the
direction of traveling of said magnetic head in relation to
said magnetic recording medium during recording, Br × t was
5   more than 9.6 mA (120 gauss·micron), sufficient writing was
impossible, overwriting characteristics were deteriorated,
and the output particularly in a high line packing density
region is decreased.

On the other hand, when Br × t was less than 3.2
10 mA (40 gauss·micron), the reproduction output was decreased
in some cases by standing at 70℃ for 4 days, depending on
the composition or thickness of the recording layer of the
medium. Therefore, the magnetic storage was constructed so
that the product of the thickness t of the magnetic layer
15 described for the magnetic recording medium described in
each of Embodiments 1 to 7 and the residual magnetic flux
density Br measured by applying a magnetic field in the
direction of traveling of said magnetic head in relation to
said magnetic recording medium during recording, Br × t
20 might be not more than 9.6 mA (120 gauss·micron) and not
less than 3.2 mA (40 gauss·micron).

When there was used a head wherein the magneto-
resistance sensor portion of the above-mentioned magneto-
resistance effect type magnetic head had been formed
25 between two shield layers made of a soft magnetic material
and located at a distance of more than 0.2 μm from each
other, no sufficient reproduction output could be obtained
when the maximum line packing density was more than 250

kFCI. When the distance between the two shield layers made
of a soft magnetic material was less than 0.12 μm, an
element could not easily be formed because of difficulty in
processing. In view of these results, the magnetic storage
5   was constructed by using a head wherein the magneto-
resistance sensor portion had been formed between two
shield layers made of a soft magnetic material and located
at a distance of not more than 0.2 μm and not less than
0.12 μm from each other. By the use of thus constructed
10 magnetic storage, a packing density of 5 gigabits or more
per square inch could be attained.

Embodiment 9

A magnetic storage was constructed by employing
the same structure as shown in Fig. 4, except that in place
15 of the magnetoresistance effect type magnetic head used in
Embodiment 8, there was used the same magnetoresistance
effect type magnetic head 63 as described in Embodiment 8
except that it comprised a magnetoresistance sensor
comprising a plurality of electroconductive magnetic layers
20 capable of causing a marked resistance change owing to
relative changes of their mutual directions of magnetiza-
tion caused by an external magnetic field, and electrocon-
ductive nonmagnetic layers located among the electrocon-
ductive magnetic layers.

25   Fig. 7 is a cross-sectional view of the sensor
used. The structure of this sensor is such that on a gap
layer 608, a Ta buffer layer 801 of 5 nm thick, a first

magnetic layer 802 of 7 nm thick, an intermediate copper
layer 803 of 1.5 nm thick, a second magnetic layer 804 of 3
nm thick, and a Fe-50 at.% Mn antiferromagnetic alloy layer
805 of 10 nm thick are formed in that order. Ni-20 at% Fe

5   alloy was used in said first magnetic layer and cobalt was
used in the second magnetic layer 804. The magnetization
of the second magnetic layer 804 is fixed in one direction
by an exchange magnetic field from the antiferromagnetic
layer 805. On the other hand, the direction of magnetiza-

10 tion of first magnetic layer 802 contacting the second
magnetic layer 804 through the nonmagnetic layer 803 is
changed by a magnetic field leaking out of the magnetic
recording medium 61, so that a resistance change is caused.

Such a resistance change accompanying the changes

15 of relative directions of magnetization of the two magnetic
layers is called "spin valve effect". In the present
embodiment, a spin valve type magnetic head utilizing this
effect was used as the head for reproduction. The tapered
portion 705 has the same structure as in the magnetic

20 sensor used in Embodiment 8.

Br × t of magnetic recording media used for
measurement was adjusted to 3, 3.2, 4, 6, 8, 10, 12 or 14
mA. When Br × t was adjusted to 3 mA (37.5 gauss · micron),
reproduction signals were remarkably decreased with the

25 lapse of time and it was difficult to obtain a practically
desirable coercive force. It became clear that when Br × t
was more than 12 mA (150 gauss · micron), the tendency of the
output resolving power to lowering becomes remarkable

undesirably though the output of 2F was large.

When such a spin valve type reproducing head was used, a signal output could be obtained by stable reproduction of signals recorded at a maximum line packing density
5 of more than 360 kFCI, as described in Embodiment 8.

The head described above was the same as used in Embodiment 8. In the head, the magnetoresistance effect type magnetic head was formed on a magnetic head slider having an area of lifting surface rail of 1.4 mm^2 or less
10 and a mass of 2 mg or less. The reason why the area of lifting surface rail is 1.4 mm^2 or less is that the probability of collision with the above-mentioned projections is reduced and that at the same time the reliability on impact resistance can be improved by adjusting the mass
15 to 2 mg or less. Thus, both a high packing density and a high impact resistance could be attained, and a mean time between failures (MTBF) of 300,000 hours or more can be could be attained at a packing density of 5 gigabits or more per square inch.

20 Embodiment 10

A substrate 1' obtained by plating an aluminum alloy base material (outside diameter 95 mm, inside diameter 25 mm, thickness 0.8 mm) with Ni-P was textured so that Ra = 2 nm and Rp = 15 nm (Ra and Rp are indications of
25 roughness), and then it was thoroughly washed. The thus treated substrate 1' was introduced into a vacuum tank evacuated to about 5.3 $\times$ 10 E – 5 Pa (4.0 $\times$ 10 E – 7

Torr). First, the substrate 1' was conveyed to a heating chamber in the vacuum tank and heated to 260℃ with an IR heater (infrared heater).

5   Then, the substrate 1' was conveyed to a primer-layer forming chamber and a Cr-10 at.% Mo-7.5 at.% Ti alloy primer layer 2' was formed thereon in a thickness of 30 nm by a DC magnetron sputtering method under an Ar atmosphere at about 0.8 Pa (6 mTorr). Subsequently, the substrate 1' was conveyed to a magnetic-recording-layer forming chamber

10   and a Co-20 at.% Cr-4 at.% Ta-8 at.% Pt alloy layer 3' (capable of forming a magnetic layer) was formed thereon in a thickness of 22 nm by a DC magnetron sputtering method under an Ar atmosphere at about 0.9 Pa (7 mTorr).

       Using this substrate having the Cr-10 at.% Mo-7.5

15   at.% Ti alloy primer layer 2' and Co-20 at.% Cr-4 at.% Ta-8 at.% Pt alloy layer 3' formed thereon, the following protective filmy layers composed mainly of carbon according to the present invention were formed.

       As the above-mentioned substrate 1', there can be

20   used, for example, rigid substrates made of ceramics of chemically strengthened aluminosilicate, soda-lime glass, silicon, borosilicate glass, etc. or made of glass-glazed ceramics, as well as Al-Mg alloy substrates subjected to nonelectrode plating with Ni-P.

25   The primer layer 2' is used as a primer film for controlling the crystalline orientation of the magnetic layer formed thereon. As the primer layer, there can also be used thin films of Cr-based alloys such as nonmagnetic

Cr-V, Cr-Ti, Cr-Mo, Cr-Si and Cr-Mo-Ti alloys which form
disordered solid solutions capable of being subjected to
(100) orientation good in crystal matching with the
magnetic layer. When the primer layer was formed by adding
5   0.5 vol% to 50 vol% of nitrogen to a gas for discharge used
in the sputtering, the refinement of grains of the primer
layer took place. Consequently, grains of the magnetic
layer subsequently formed were also refined, so that medium
noise could be reduced.

10   As the magnetic layer 3', there can be used not
only Co-Cr-Ta-Pt alloys but also multi-component alloy
systems which are composed mainly of Co, contain Pt for
increasing the coercive force and contain Cr, Ta, SiO_2, Nb,
etc. for reducing medium noise. Particularly when Ta, Nb,
15 V or Ti was added, the melting point of a target was
lowered, so that the progress of component separation of
the magnetic layer containing Cr was desirably facilitated.

        Co-based alloy systems containing Pt, Ni or Mn
are practical because their anisotropy energy does not
20 decrease so much as that of Co-based alloy systems contain-
ing any other additive element. Specifically, there can be
used alloys such as Co-Cr-Pt-Ta, Co-Cr-Pt-SiO_2, Co-Cr-Pt-Mn,
Co-Cr-Nb-Pt, Co-Cr-V-Pt, Co-Cr-Ti-Pt, Co-Cr-Nb-Ta-Pt,
Co-Pt-Ni-SiO_2, etc., as well as Co-Cr-Pt. As to the
25 composition of the Co alloy layer constituting the ferro-
magnetic portion, the amount of Cr incorporated as a solid
solution is considered to be 5 to 10 at.% and the amount of
Ta incorporated as a solid solution about 2 at.%. When the

Co alloy magnetic layer is formed by incorporating Cr and
Ta in amounts larger than the above amounts, magnetic
separation in the magnetic layer proceeds, resulting in
reduced medium noise.

5   As a practical composition, there can be used,
for example,

Co-20 at.% Cr-4 at.% Ta-8 at.% Pt alloy,

Co-22 at.% Cr-20 at.% Pt alloy,

Co-15 at.% Cr-8 at.% Pt-20 mol.% SiO_2 alloy,

10   Co-17 at.% Cr-12 at.% Pt-5 at.% Mn alloy,

Co-17 at.% Cr-5 at.% Nb-10 at.% Pt alloy,

Co-20 at.% Cr-5 at.% V-12 at.% Pt alloy,

Co-20 at.% Cr-10 at.% V-15 at.% Pt alloy, and

Co-15 at.% Cr-5 at.% Nb-5 at.% Ta-20 at.% Pt alloy.

15   The above-mentioned substrate was conveyed to the
protective-filmy-layer forming chamber 31' shown in Fig.
10, without taking out the substrate from the vacuum tank.
Ar gas containing 30% N_2 and 6.0% H_2 was introduced into the
chamber 31' at a rate of 24 sccm through a mass flow

20   controller while evacuating the protective-filmy-layer
forming chamber 31' with a turbo molecular pump. In this
case, the pressure was about 1 Pa (8 mTorr) as measured
with a Baratron gauge.

          Then, DC 1000 W was applied to graphite sintering
25   targets fixed on cathodes located on both sides of the
substrate, to induce plasma. In this case, the discharge
current was about 1.5 A and the discharge voltage about 670
V. By this so-called reactive sputtering method, an

amorphous carbon protective filmy layer 5' composed mainly
of carbon and nitrogen and containing hydrogen was formed
in a thickness of 6 nm on the Co-Cr-Ta-Pt alloy layer 3'.
In this case, the build-up rate of the film was 0.8 nm/s.

5   Next, the thus treated substrate was conveyed to
a protective-filmy-layer forming chamber 21'. The
protective-filmy-layer forming chamber 21' is composed of
ion guns consisting of a hot filament 22', an anode 23' and
a grid 24' located in front of the hot filament. The

10   protective-filmy-layer forming chamber 21' is also equipped
with the shields against deposited particles 25' shown in
Fig. 13, so as to have such a structure that a film is
actively built up only outside a disc radius of 45.5 mm on
the substrate and that build-up of a film is very difficult

15   within a disc radius of 45.5 mm. From behind the anode, Ar
gas and ethylene (C_2H_4) gas were introduced into the chamber
21', each at a rate of 15 sccm, through a mass flow
controller while evacuating the protective-filmy-layer
forming chamber 21' with a turbo molecular pump. In this

20   case, the pressure was about 0.5 Pa (4 mTorr) as measured
with a Baratron gauge.

          Then, plasma was induced by applying 350 mA and
direct current +120 V to the hot filament and anode,
respectively, of each of the ion guns located on both sides

25   of the substrate. Ions were extracted by applying -530 V
to the grids. Further, a pulse bias of -80 V and 3 kHz was
applied to the substrate. In this case, the anode current
was 500 mA and the bias current of the substrate was 120

mA. By this so-called ion beam deposition method (IBD), a
DLC protective filmy layer 5' composed mainly of carbon and
hydrogen was formed in a thickness of 5 nm outside a disc
radius of 45.5 mm on the protective filmy layer 4'. In
5   this case, the build-up rate of the film was 1.0 nm/s.
Consequently, the protective filmy layers were combined as
follows: a two-layer structure having a total thickness of
11 nm was formed of the amorphous carbon layer and the DLC
layer outside a disc radius of 45.5 mm, and the amorphous
10   carbon layer having a thickness of 6 nm was present alone
within a disc radius of 45.5 mm. The thus treated
substrate was taken out of the vacuum tank and allowed to
cool to room temperature spontaneously.

A plurality of discs were produced in the manner
15   described above. Some of them were used for analyzing
their protective filmy layers. Some others were subjected
to tape cleaning and then provided with a layer of about 2
nm thick of a fluorocarbon type lubricant, and after
lifting check, they were subjected to a sliding test singly
20   or subjected to a reliability test after being incorporated
into a magnetic disc apparatus.

The total thickness of the protective filmy
layers of the disc produced in the manner described above
was measured with an ellipsometer at a 0.1-mm pitch from
25   the ramp load area to the area other than the area where
ramp load was carried out, i.e., the so-called data area
where the protective film did not steadily come into
contact with a magnetic head. As a result, it was found

that the transient area where 90% of the thickness in the
ramp load area, i.e., 9.9 nm, decreased to 110% of the
thickness in the data area, i.e., 6.6 nm, had a length of
2.4 mm in the radial direction. Raman spectroscopic

5 analysis was carried out in order to investigate the
structures of the protective filmy layers of the disc
produced in the manner described above. For the sake of
simplicity, there were used a disc having no protective
filmy layer 4' formed thereon and a disc having no protec-

10 tive filmy layer 5' formed thereon. There were employed
Raman spectroscopic analysis apparatus 2010 manufactured by
Lennie-Shaw Co., an Ar laser (514.5 nm), and a measuring
wave number of 1000 to 1800, or 1000 to 2300/cm.

As a result, by the same fact as described in

15 Embodiment 6, it could be confirmed that the protective
filmy layer 4' was a typical DLC film as shown in Fig. 11.
By the same fact as described in Embodiment 6, it could
also be confirmed that the protective filmy layer 5' was an
amorphous carbon layer containing both a large amount of

20 nitrogen and hydrogen, as shown in Fig. 12.

On the other hand, ten of the discs also having
the lubricant layer formed thereon were individually set in
a ramp load evaluation apparatus and tested. When the 10
discs were subjected to ramp load 50,000 times at a

25 revolution rate of 7,500 r.p.m., all of the 10 discs
finished the test without crash. When their surfaces after
the test were carefully observed under a microscope and
carefully and visually observed by oblique light, no injury

was detected in the discs. Thus, it was proved that the magnetic recording medium of the present invention has a sufficient reliability on resistance to sliding when the thickness of the protective film in the area where a

5   magnetic head performs ramp load is 11 nm.

Next, 0.1 g of alumina particles having an average particle size of 0.1 μm were casted on each of the 10 discs while carrying out random seeking of a magnetic head at 7,500 r.p.m. in the area other than the area where

10   ramp load was carried out, i.e., the so-called data area (corresponding to a disc radius range of 21 mm to 45.5 mm) where the protective film did not steadily come into contact with the magnetic head. After 120 seconds of the seeking, the disc surface was observed under a microscope

15   and visually observed by oblique light. As a result, it was found that although the surface of the protective film had received some very slight scratches, so-called crash accompanying the fracture of the protective film had not occurred. Thus, it was proved that the magnetic recording

20   medium of the present invention can have a sufficient reliability on resistance to sliding though the thickness of the protective filmy layer in the data area is as very small as 6 nm.

As explained above, Embodiments of the present

25   invention include the following examples of constitutions.

A process for producing a magnetic recording medium comprising a substrate, a magnetic film formed thereon and a protective film formed thereon for the

protection of said magnetic film and composed mainly of carbon, which comprises forming a filmy layer as a portion of said protective film where said protective film comes into contact with a magnetic head at the time of starting

5 or standing of said magnetic head, by an ion beam method using either only a hydrocarbon gas or a combination of a hydrocarbon gas and at least one of Ne, Ar, Kr and Xe, and then forming another protective filmy layer capable of constituting substantially the whole surface of said

10 magnetic recording medium, by a sputtering method using N_2 and at least one of H_2, Ne, Ar, Kr and Xe.

A process for producing a magnetic recording medium comprising a substrate, a magnetic film formed thereon and a protective film formed thereon for the

15 protection of said magnetic film and composed mainly of carbon, which comprises forming a protective filmy layer capable of constituting substantially the whole surface of said magnetic recording medium, by a sputtering method using N_2 and at least one of H_2, Ne, Ar, Kr and Xe, and then

20 forming another filmy layer thereon as a portion of said protective film where said protective film comes into contact with a magnetic head at the time of starting or standing of said magnetic head, by an ion beam method using either only a hydrocarbon gas or a combination of a hydro-

25 carbon gas and at least one of Ne, Ar, Kr and Xe.

A magnetic recording medium comprising a substrate, a magnetic film formed thereon and a protective film formed thereon for the protection of said magnetic

film and composed mainly of carbon, wherein a portion of
said protective film where said protective film comes into
contact with a magnetic head at the time of starting or
standing of said magnetic head comprises a diamond-like
5 (DLC) layer composed mainly of carbon and hydrogen and an
amorphous carbon layer composed mainly of carbon and
nitrogen and containing hydrogen, and the portion other
than said contact portion of said protective film comprises
an amorphous carbon layer composed mainly of carbon and
10 nitrogen and containing hydrogen.

    A magnetic recording medium comprising a
substrate, a magnetic film formed thereon and a protective
film formed thereon for the protection of said magnetic
film and composed mainly of carbon, wherein the thickness
15 of the other portion of said protective film than a portion
where said protective film comes into contact with a
magnetic head at the time of starting or standing of said
magnetic head is 10 nm or less, the thickness of the
portion of said protective film where said protective film
20 comes into contact with a magnetic head at the time of
starting or standing of said magnetic head is larger than
that of the portion other than said contact portion of said
protective film and is 20 nm or less, and the rate of
thickness change in the radial direction of said protective
25 film in the boundary between said contact portion of said
protective film and the portion other than said contact
portion of said protective film is higher than the rate of
thickness change in the radial direction of said protective

film in the portion other than said contact portion of said
protective film and has a value of 1.0 nm/mm or more.

    According to the present invention, it is
possible to obtain a magnetic recording medium which
5 permits high-density recording and has an excellent
reliability, as a magnetic recording medium comprising a
substrate, a magnetic film formed thereon and a protective
film formed thereon for the protection of said magnetic and
composed mainly of carbon, wherein a portion of said
10 protective film where a magnetic head comes into contact
with said protective film at the time of starting and/or
standing of the magnetic head is composed mainly of carbon
and nitrogen, the other portion is composed mainly of
carbon, nitrogen and hydrogen, the hardness of the portion
15 where a magnetic head comes into contact with said protec-
tive film at the time of starting and/or standing of the
magnetic head is less than 19 Gpa and not less than 15 Gpa
as measured in a definite-indentation-depth mode by using a
Barkovich type diamond indenter, the hardness of the other
20 portion of said protective film is 19 Gpa or more, and the
thickness of the other portion of said protective film than
the portion where a magnetic head comes into contact with
said protective film at the time of starting and/or stand-
ing of the magnetic head is 15 nm or less.

25   Said protective film can be obtained by forming a
film composed mainly of carbon, hydrogen and nitrogen, and
then laminating another film composed mainly of carbon and
nitrogen on the film composed mainly of carbon, hydrogen

and nitrogen, as the portion of the protective film where a
magnetic head comes into contact with said protective film
at the time of starting and/or standing of the magnetic
head.

5   Said protective film can be formed by forming a
film by a sputtering method using H_2 in addition to either
only N_2 or a combination of N_2 and at least one of Ne, Ar,
Kr and Xe, and forming another film thereon by a sputtering
method using either only N_2 or a combination of N_2 and at
10   least one of Ne, Ar, Kr and Xe, after taking a means for
preventing the adhesion of sputtering particles in the
other portion of the protective film than a portion where a
magnetic head comes into contact with the protective film
at the time of starting and/or standing of the magnetic
15   head.

     In addition, a magnetic disc apparatus having
high capacity and reliability can be provided by combining
said magnetic recording medium with a magnetic head.

     Furthermore, according to the present invention,
20   it is possible to obtain a process for producing a magnetic
recording medium which permits high-density recording and
has an excellent reliability, as a process for producing a
magnetic recording medium comprising a substrate, a
magnetic film formed thereon and a protective film formed
25   thereon for the protection of said magnetic film and
composed mainly of carbon, which comprises forming a filmy
layer as a portion of said protective film where said
protective film comes into contact with a magnetic head at

the time of starting or standing of said magnetic head, by
an ion beam method using either only a hydrocarbon gas or a
combination of a hydrocarbon gas and at least one of Ne,
Ar, Kr and Xe, and then forming another protective filmy

5   layer capable of constituting substantially the whole
surface of the above-mentioned magnetic recording medium,
by a sputtering method using N_2 and at least one of H_2, Ne,
Ar, Kr and Xe; or which comprises forming a protective
filmy layer capable of constituting substantially the whole

10   surface of the above-mentioned magnetic recording medium,
by a sputtering method using N_2 and at least one of H_2, Ne,
Ar, Kr and Xe, and then forming another filmy layer thereon
as a portion of said protective film where said protective
film comes into contact with a magnetic head at the time of

15   starting or standing of said magnetic head, by an ion beam
method using either only a hydrocarbon gas or a combination
of a hydrocarbon gas and at least one of Ne, Ar, Kr and Xe.

Since the portion of said protective film where
said protective film comes into contact with a magnetic

20   head at the time of starting or standing of said magnetic
head is formed by the ion beam method, the boundary portion
between said contact portion and the other portion can be
formed so as to have a steep curved surface. Therefore,
the recording area can be efficiently extended.